CHAPTER 5

DIESEL FUEL SYSTEMS

LEARNING OBJECTIVE: Describe *the different type of diesel fuel systems, how the components function to provide fuel to the engine in proper quantities, and servicing of the diesel fuel systems.*

Maintenance personnel form part of an important network of dedicated people who ensure that medium- and heavy-duty trucks and construction equipment are kept in a state of safe and acceptable performance standards. The diesel fuel injection system is a major component of a properly operating engine. An engine out of adjustment can cause excessive exhaust smoke, poor fuel economy, heavy carbon buildup within the combustion chambers, and short engine life.

DIESEL FUEL SYSTEMS

LEARNING OBJECTIVE: *Identify the properties of diesel fuel. Describe the function and operation of governors and fuel system components.*

Like the gasoline engine, the diesel engine is an internal combustion engine using either a two- or four-stroke cycle. Burning or combustion of fuel within the engine cylinders obtains power. The diesel engine does not use a carburetor because the diesel fuel is mixed in the cylinder with compressed air.

Compression ratios in the diesel engine range between 14:1 and 19:1. This high ratio causes increased compression pressures of 400 to 600 psi and cylinder temperature reach 800°F to 1200°F. At the proper time, the diesel fuel is injected into the cylinder by a fuel injection system, which usually consists of a pump, fuel line, and injector or nozzle. When the fuel oil enters the cylinder, it will ignite because of the high temperatures. The diesel engine is known as a COMPRESSION-IGNITION engine, while the gasoline engine is a SPARK-IGNITION engine.

Figure 5-1 shows the comparison of the four strokes of a four-cycle diesel engine and a four-cycle gasoline engine.

The speed of a diesel engine is controlled by the amount of fuel injected into the cylinders. In a gasoline engine, the speed of the engine is controlled by the amount of air admitted into the carburetor or gasoline fuel injection systems.

Mechanically, the diesel engine is similar to the gasoline engine. The intake, compression, power, and exhaust strokes occur in the same order. The arrangement of the pistons, connecting rods, crankshaft, and engine valves is about the same. The diesel engine is also classified as IN-LINE or V-TYPE.

In comparison to the gasoline engine, the diesel engine produces more power per pound of fuel, is more reliable, has lower fuel consumption per horsepower per hour, and presents less of a fire hazard.

These advantages are partially offset by higher initial cost, heavier construction needed for its high compression pressures, and the difficulty in starting which results from these pressures.

DIESEL FUEL

Diesel fuel is heavier than gasoline because it is obtained from the residue of the crude oil after the more volatile fuels have been removed. As with gasoline, the efficiency of diesel fuel varies with the type of engine in which it is used. By distillation, cracking, and blending of several oils, a suitable diesel fuel can be obtained for all engine operating conditions. Using a poor or improper grade of fuel can cause hard starting, incomplete combustion, a smoky exhaust, and engine knocks.

The high injection pressures needed in the diesel fuel system result from close tolerances in the pumps and injectors. These tolerances make it necessary for the diesel fuel to have sufficient lubrication qualities to prevent rapid wear or damage. It must also be clean,

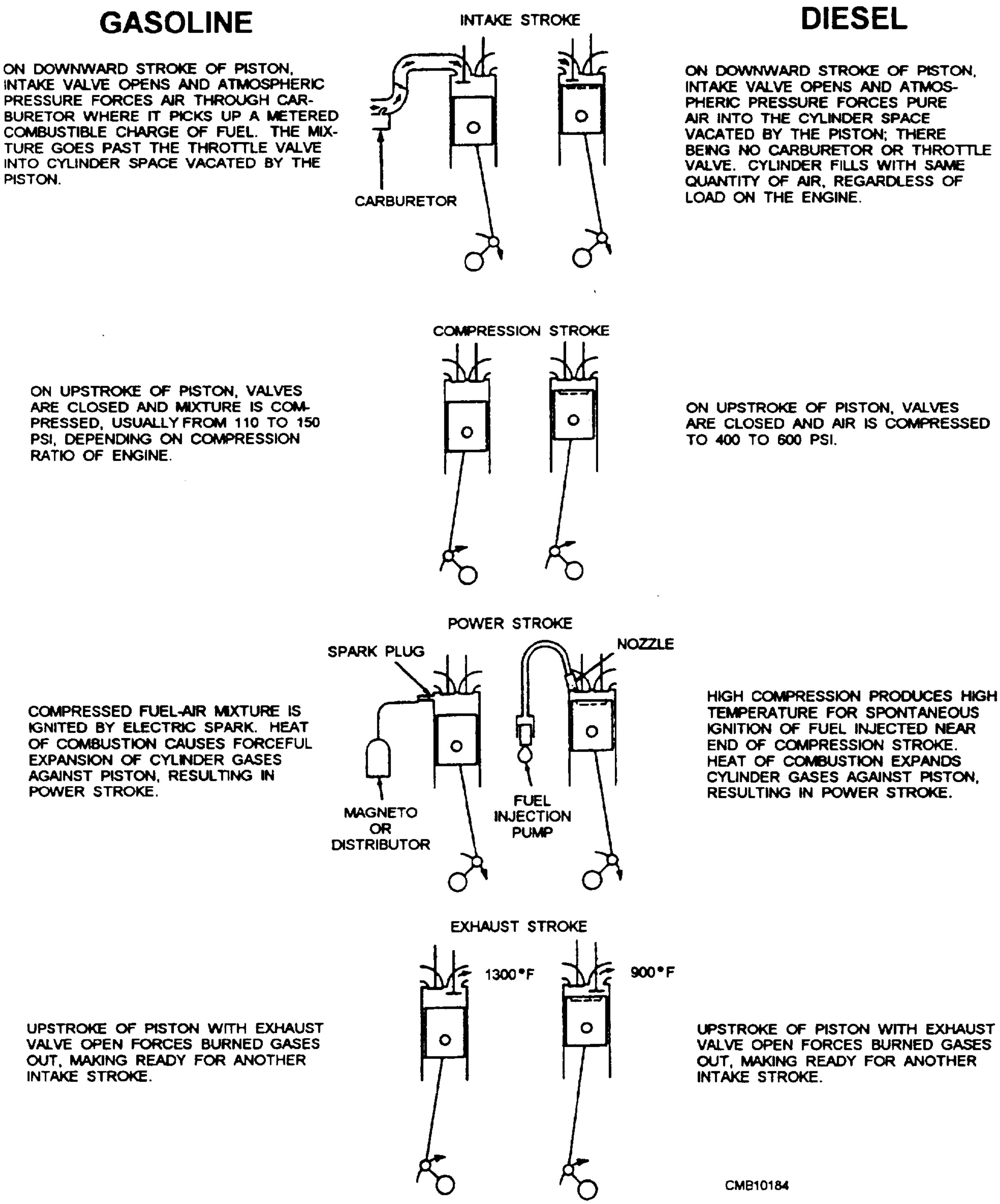


Figure 5-1.—Comparison of sequence of events in diesel and gasoline four-cycle engines.

mix rapidly with the air, and burn smoothly to produce an even thrust on the piston during combustion.

Diesel Fuel Oil Grades

Diesel fuel is graded and designated by the American Society for Testing and Materials (ASTM), while its specific gravity and high and low heat values are listed by the American Petroleum Institute (API). Each individual oil refiner and supplier attempts to produce diesel fuels that comply as closely as possible with ASTM and API specifications. Because of different crude oil supplies, the diesel fuel may be on either the high or low end of the prescribed heat scale in Btu per pound or per gallon. Because of deterioration of diesel fuel, there are only two recommended grades of fuel that is considered acceptable for use in high-speed heavy-duty vehicles. These are the No. 1D or No. 2D fuel oil classification

Grade No. 1D comprises the class of volatile fuel oils from kerosene to the intermediate distillates. Fuels within this classification are applicable for use in high-speed engines in service involving frequent and relatively wide variations in loads and speeds. In cold weather conditions, No. 1D fuel allows the engine to start easily. In summary, for heavy-duty high-speed diesel vehicles operating in continued cold-weather conditions, No. 1D fuel provides better operation than the heavier No. 2D.

Grade No. 2D includes the class of distillate oils of lower volatility. They are applicable for use in high-speed engines in service involving relatively high loads and speeds. This fuel is used more by truck fleets, due to its greater heat value per gallon, particularly in warm to moderate climates. Even though No. 1D fuel has better properties for cold weather operations, many still use No. 2D in the winter, using fuel heater/water separators to provide suitable starting, as well as fuel additive conditioners, which are added directly into the fuel tank.

Selecting the correct diesel fuel is a must if the engine is to perform to its rated specifications. Generally, the seven factors that must be considered in the selection of a fuel oil are as follows:

1. Starting characteristics
2. Fuel handling
3. Wear on injection equipment
4. Wear on pistons
5. Wear on rings, valves, and cylinder liners
6. Engine maintenance
7. Fuel cost and availability

Other considerations in the selection of a fuel oil are as follows:

- Engine size and design
- Speed and load range
- Frequency of load and speed changes
- Atmospheric conditions

Cetane Number

Cetane number is a measure of the fuel oils volatility; the higher the rating, the easier the engine will start and the combustion process will be smoother within the ratings specified by the engine manufacturer. Current 1D and 2D diesel fuels have a cetane rating between 40 and 45.

Cetane rating differs from octane rating that is used in gasoline in that the higher the number of gasoline on the octane scale, the greater the fuel resistance to self-ignition, which is a desirable property in gasoline engines with a high compression ratio. Using a low octane fuel will cause pm-ignition in high compression engines. However, the higher the cetane rating, the easier the fuel will ignite once injected into the diesel combustion chamber. If the cetane number is too low, you will have difficulty in starting. This can be accompanied by engine knock and puffs of white smoke during warm-up in cold weather.

High altitudes and low temperatures require the use of diesel fuel with an increased cetane number. Low temperature starting is enhanced by high cetane fuel oil in the proportion of 1.5°F—lower starting temperature for each cetane number increase in the fuel.

Volatility

Fuel volatility requirements depend on the same factors as cetane number. The more volatile fuels are best for engines where rapidly changing loads and speeds are encountered. Low volatile fuels tend to give better fuel economy where their characteristics are needed for complete combustion and will produce less smoke, odor, deposits, crankcase dilution, and engine wear.

The volatility of a fuel is established by a distillation test where a given volume of fuel is placed into a container that is heated gradually. The readiness with which a liquid changes to a vapor is known as the volatility of the liquid The 90 percent distillation temperature measures volatility of diesel fuel. This is the temperature at which 90 percent of a sample of the fuel has been distilled off. The lower the distillation temperature, the higher the volatility of the fuel. In small diesel engines higher fuel volatility is needed than in larger engines in order to obtain low fuel consumption, low exhaust temperature, and minimum exhaust smoke.

Viscosity

The viscosity is a measure of the resistance to flow of the fuel, and it will decrease as the fuel oil temperature increases. What this means is that a fluid with a high viscosity is heavier than a fluid with low viscosity. A high viscosity fuel may cause extreme pressures in the injection systems and will cause reduced atomization and vaporization of the fuel spray.

The viscosity of diesel fuel must be low enough to flow freely at its lowest operational temperature, yet high enough to provide lubrication to the moving parts of the finely machined injectors. The fuel must also be sufficiently viscous so that leakage at the pump plungers and dribbling at the injectors will not occur. Viscosity also will determine the size of the fuel droplets, which, in turn, govern the atomization and penetration qualities of the fuel injector spray.

Recommended fuel oil viscosity for high-speed diesel engines is generally in the region of 39 SSU (Seconds Saybolt Universal) which is derived from using a Saybolt Viscosimeter to measure the time it takes for a quantity of fuel to flow through a restricted hole in a tube. A viscosity rating of 39 SSU provides good penetration into the combustion chamber, atomization of fuel, and suitable lubrication.

Sulfur Content

Sulfur has a definite effect on the wear of the internal components of the engine, such as piston ring, pistons, valves, and cylinder liners. In addition a high sulfur content fuel requires that the engine oil and filter be changed more often. This is because the corrosive effects of hydrogen sulfide in the fuel and the sulfur dioxide or sulfur triioxide that is formed during the combustion process combines with water vapor to form acids. High additive lubricating oils are desired when high sulfur fuels are used. Refer to the engine manufacturer's specifications for the correct lube oil when using high sulfur fuel.

Sulfur content can only be established by chemical analysis of the fuel. Fuel sulfur content above 0.4% is considered as medium or high and anything below 0.4% is low. No. 2D contains between 0.2 and 0.5% sulfur, whereas No. 1D contains less than 0.1%.

Sulfur content has a direct bearing on the life expectancy of the engine and its components. Active sulfur in diesel fuel will attack and corrode injection system components in addition to contributing to combustion chamber and injection system deposits.

Cloud and Pour Point

Cloud point is the temperature at which wax crystals in the fuel (paraffin base) begin to settle out with the result that the fuel filter becomes clogged. This condition exists when cold temperatures are encountered and is the reason that a thermostatically controlled fuel heater is required on vehicles operating in cold weather environments. Failure to use a fuel heater will prevent fuel from flowing through the filter and the engine will not run. Cloud point generally occurs 9-14°F above the pour point.

Pour point of a fuel determines the lowest temperature at which the fuel can be pumped through the fuel system. The pour point is 5°F above the level at which oil becomes a solid or refuses to flow.

Cleanliness and Stability

Cleanliness is an important characteristic of diesel fuel. Fuel should not contain more than a trace of foreign substances; otherwise, fuel pump and injectors difficulties will develop leading to poor performance or seizure. Because it is heavier and more viscous, diesel fuel will hold dirt particles in suspension for a longer period than gasoline. Moisture in the fuel can also damage or cause seizure of injector parts when corrosion occurs.

Fuel stability is its capacity to resist chemical change caused by oxidation and heat. Good oxidation stability means that the fuel can be stored for extended periods of time without the formation of gum or sludge. Good thermal stability prevents the formation or carbon in hot parts, such as fuel injectors or turbine nozzles. Carbon deposits disrupt the spray patterns and cause inefficient combustion.

COMBUSTION CHAMBER DESIGN

The fuel injected into the combustion chamber must be mixed thoroughly with the compressed air and

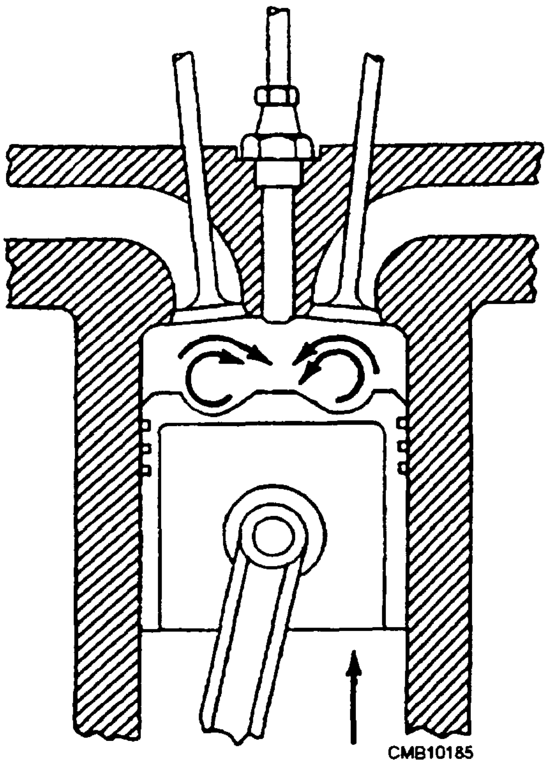


Figure 5-2.—Open combustion chamber.

distributed as evenly as possible throughout the chamber if the engine is to function at maximum efficiency and exhibit maximum drivabilty. A well-designed engine uses a combustion chamber that is designed for the intended usage of the engine. The injects used should compliment the combustion chamber. The combustion chambers described on the following pages are the most common and cover virtually all of the designs that are currently in use. These are the open chamber, precombustion chamber, turbulence chamber, and spherical (hypercycle) chamber.

Open Combustion Chamber

The open combustion chamber (fig. 5-2) is the simplest form of chamber. It is suitable for only slow-speed, four-stroke cycle engines, but is widely used in two-stroke cycle diesel engines. In the open chamber, the fuel is injected directly into the space on top of the cylinder. The combustion space, formed by the top of the piston and the cylinder head, usually is shaped to provide s swirling action of the air, as the piston comes up on the compression stroke. There are no special pockets, cells, or passages to aid the mixing of the fuel and air. This type of chamber requires a higher injection pressure and a greater degree of fuel atomization than is required by other combustion chambers to obtain an acceptable level of fuel mixing. To equalize combustion in the combustion chamber, use a multiple orifice-type injector tip for effective penetration. This chamber design is very susceptible to ignition lag.

Precombustion Chamber

The precombustion chamber (fig. 5-3) is an auxiliary chamber at the top of the cylinder. It is connected to the main combustion chamber by a restricted throat or passage. The precombustion chamber conditions the fuel for final combustion in the cylinder. A hollowed-out portion of the piston top

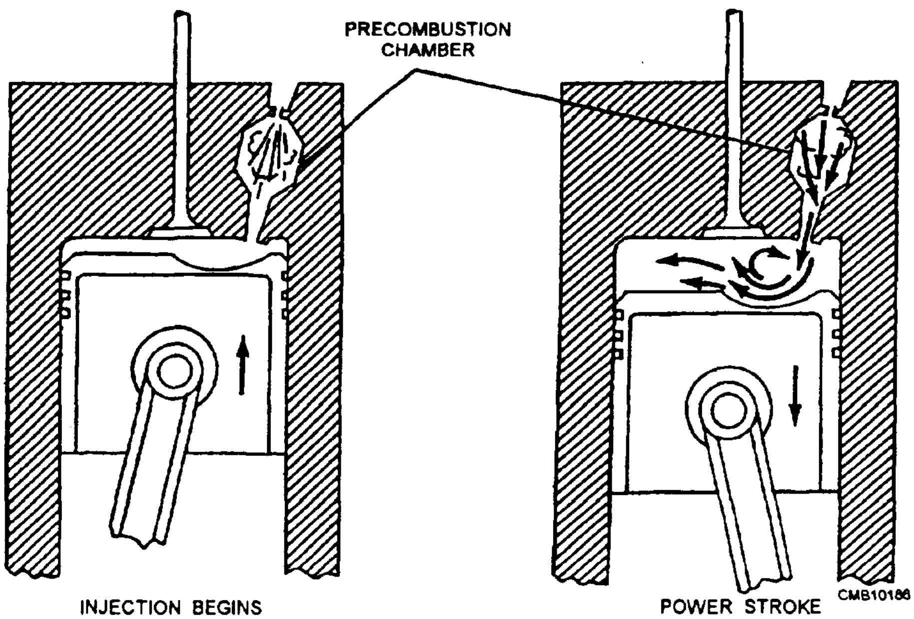


Figure 5-3.—Precombustion chamber.

causes turbulence in the main combustion chamber, as the fuel enters from the precombustion chamber to aid in mixing with air. The following steps occur during the precombustion process:

- During the compression stroke of the engine, air is forced into the precombustion chamber and, because the air is compressed, it is hot. At the beginning of injection, the precombustion chamber contains a definite volume of air.
- As the injection begins, combustion begins in the precombustion chamber. The burning of the fuel, combined with the restricted passage to the main combustion chamber, creates a tremendous amount of pressure in the combustion chamber. The pressure and the initial combustion cause a super-heated fuel charge to enter the main combustion chamber at a high velocity.
- The entering mixture hits the hollowed-out piston top, creating turbulence in the chamber to ensure complete mixing of the fuel charge with the air. This mixing ensures even and complete combustion. This chamber design provides satisfactory performance with low fuel injection pressures and coarse spray patterns because a large amount of vaporization occurs in the precombustion chamber. This chamber also is not very susceptible to ignition lag, making it suitable for high-speed operations.

Turbulence Chamber

The turbulence chamber (fig. 54) is similar in appearance to the precombustion chamber, but its function is different. There is very little clearance between the top of the piston and the head, so a high percentage of the air between the piston and cylinder head is forced into the turbulence chamber during the compression stroke. The chamber is usually spherical, and the small opening through which the air must pass causes an increase in air velocity, as it enters the chamber. This turbulence speed is about 50 times crankshaft speed. The fuel injection is timed to occur when the turbulence in the chamber is greatest. This ensures a thorough mixing of the fuel and air, causing the greater part of combustion to take place in the turbulence chamber. The pressure, created by the expansion of the burning gases, is the force that drives the piston downward on the power stroke.

Spherical (Hypercycle) Chamber

The spherical (hypercycle) combustion chamber (fig. 5-5) is designed principally for use in the multifuel diesel engine. The chamber consists of a basic open type chamber with a spherical shaped relief in the top of the piston head. The chamber works in conjunction with a strategically positioned injector and an intake port that produces a swirling effect, as it enters the chamber. Operation of the chamber is as follows:

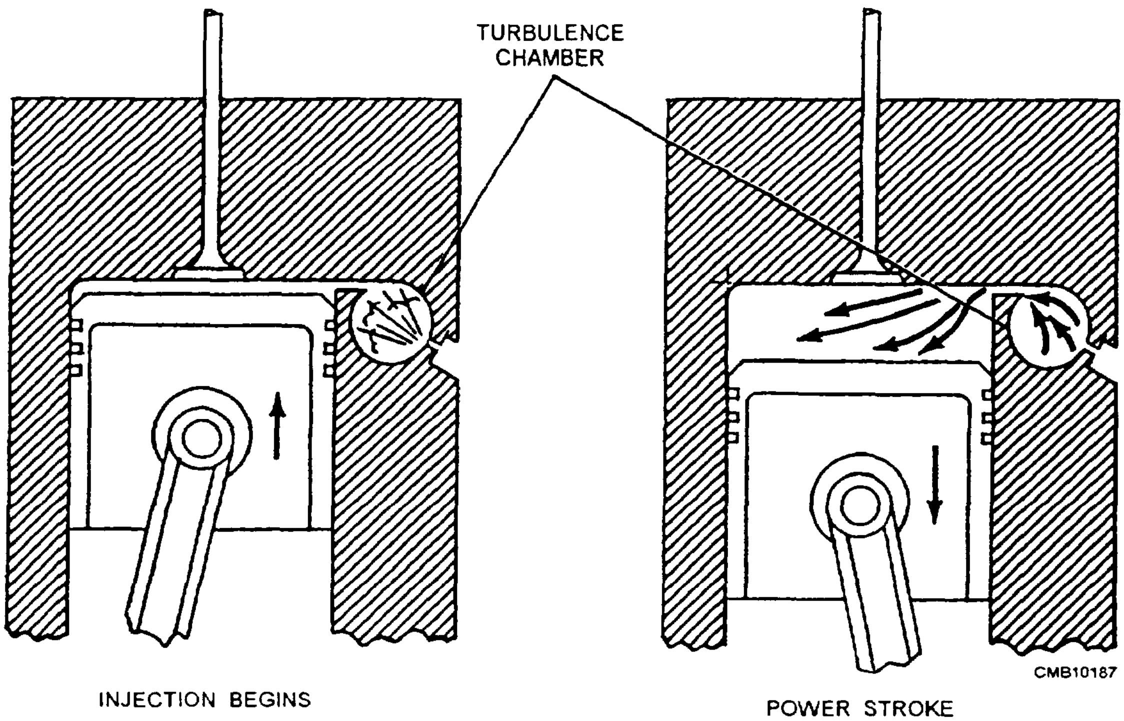


Figure 5-4.—Turbulence chamber.

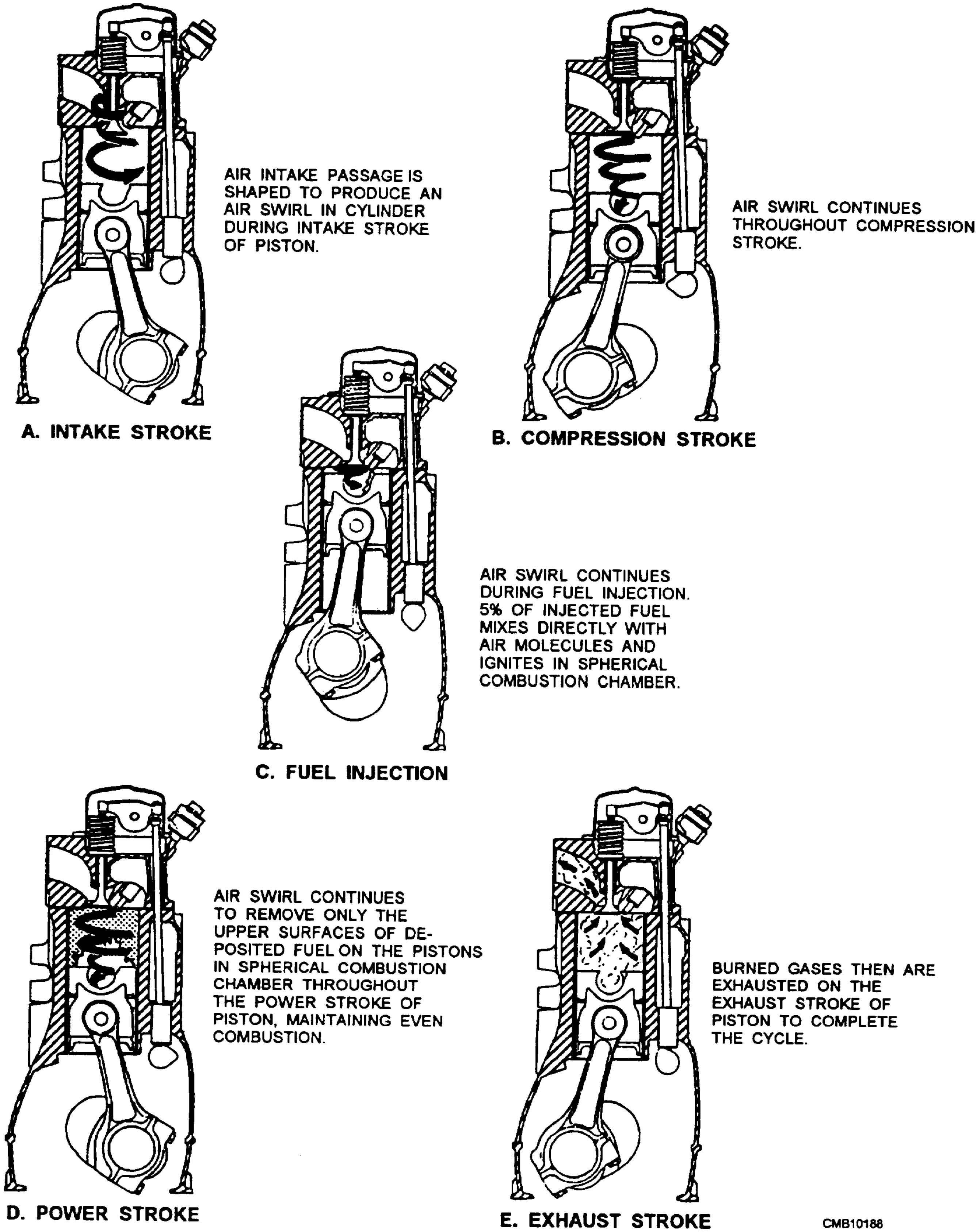


Figure 5-5.—Spherical chamber.

1. As the air enters the combustion chamber, the shape of the intake port (fig. 5-5) introduces a swirling effect to it.
2. During the compression stroke, the swirling motion of the air continues as the temperature in the chamber increases (fig. 5-5).
3. As the fuel is injected, approximately 95 percent of it is deposited on the head of the piston and the remainder mixes with the air in the spherical combustion chamber (fig. 5-5).
4. As combustion begins, the main portion of the fuel is swept off the piston head by the high-velocity swirl that was created by the intake and the compression strokes. As the fuel is swept off of the head, it burns through the power stroke, maintaining even combustion and eliminating detonation (fig. 5-5).

GOVERNORS

A governor is required on a diesel engine to control the idling and maximum speeds of the engine, with some governors being designed to control the speed within the overall operating range of the engine. It is possible for the operator to control the engine speed between idle and maximum through the operation of the throttle. Idle and maximum speeds must be controlled to prevent the engine from stalling during low-speed idle and to keep the speed from exceeding the maximum desired limits desired by the manufacturer. The main reason that a diesel requires a governor is that a diesel engine operates with excess air under all loads and speeds.

Even though it is not part of the fuel system, a governor is directly related to this system since it functions to regulate speed by the control of fuel or of the air-fuel mixture, depending on the type of engine. In diesel engines governors are connected in the linkage between the throttle and the fuel injectors. The governor acts through the fuel injection equipment to regulate the amount of fuel delivered to the cylinders. As a result the governor holds engine speed reasonably constant during fluctuations in load.

Before discussing governor types and operations, governor terms should be addressed and understood since they are commonly used when discussing engine speed regulation.

Terms

To understand why different types of governors are needed for different kinds of job, you will need to know the meaning of several terms that are used in describing the characteristics of action of the governor.

- **Maximum no-load speed** or high idle is used to describe the highest engine rpm obtainable when the throttle linkage is moved to its maximum position with no load applied to the engine.
- **Maximum full-load speed** or rated speed is used to indicate the engine rpm at which a particular engine will produce its maximum designed horsepower setting as stated by the manufacturer.
- **Idle** or low-idle speed is used to indicate the normal speed at which the engine will rotate with the throttle linkage in the released or closed position,
- **Work capacity** is used to describe the amount of available work energy that can be produced to the output shaft of the governor.
- **Stability** refers to the ability of the governor to maintain speed with either constant or varying loads without hunting.
- **Speed droop** is used to express the difference in the change in the governor rotating speed which causes the output shaft of the governor to move from its full-open throttle position to its full-closed position or vice versa.
- **Hunting** is a repeated and sometimes rhythmic variation of speed due to overcontrol by the governor. Also called speed drift.
- **Sensitivity** is an expression of how quickly the governor responds to a speed change.
- **Response time** is normally the time taken in seconds for the fuel linkage to be moved from a no-load to a full-load position.
- **Isochronous** is used to indicate zero-droop capability. In others words, the full-load and no-load speeds are the same.
- **Overrun** is used to express the action of the governor when the engine exceeds its maximum governed speed.

- **Underrun** is a simple term to describe the ability of the governor to prevent engine speed from dropping below a set idle, particularly when the throttle has been moved rapidly to a decreased fuel setting from maximum full-load position.

- **Deadband** is the change in speed required before the governor will make a corrective movement of the throttle.

- **State of balance** is used to describe the speed at which the centrifugal force of the rotating flyweights of the governor matches and balances the spring force of the governor.

Types of Governors

The type of governor used on diesel engines is dependent upon the application required. The six basic types of governors are as follows:

1. Mechanical centrifugal flyweight style that relies on a set of rotating flyweights and a control spring; used since the inception of the diesel engine to control its speed.
2. Power-assisted servomechanical style that operates similar to the mechanical centrifugal flyweight but uses engine oil under pressure to move the operating linkage.
3. Hydraulic governor that relies on the movement of a pilot valve plunger to control pressurized oil flow to a power piston, which, in turn, moves the fuel control mechanism.
4. Pneumatic governor that is responsive to the air flow (vacuum) in the intake manifold of an engine. A diaphragm within the governor housing is connected to the fuel control linkage that changes its setting with increases or decreases in the vacuum.
5. Electromechanical governor uses a magnetic speed pickup sensor on an engine-driven component to monitor the rpm of the engine. The sensor sends a voltage signal to an electronic control unit that controls the current flow to a mechanical actuator connected to the fuel linkage.
6. Electronic governor uses magnetic speed sensor to monitor the rpm of the engine. The sensor continuously feeds information back to the ECM (electronic control module). The ECM then computes all the information sent from all other engine sensors, such as the throttle position sensor, turbocharger-boost sensor, engine oil pressure and temperature sensor, engine coolant sensor, and fuel temperature to limit engine speed.

The governors, used on heavy-duty truck applications and construction equipment, fall into one of two basic categories:

1. Limiting-speed governors, sometimes referred to as minimum/maximum models since they are intended to control the idle and maximum speed settings of the engine. Normally there is no governor control in the intermediate range, being regulated by the position of the throttle linkage.
2. Variable-speed or all range governors that are designed to control the speed of the engine regardless of the throttle setting.

Other types of governors used on diesel engines are as follows:

1. Constant-speed, intended to maintain the engine at a single speed from no load to full load.
2. Load limiting, to limit the load applied to the engine at any given speed. Prevents overloading the engine at whatever speed it may be running.
3. Load-control, used for adjusting to the amount of load applied at the engine to suit the speed at which it is set to run.
4. Pressure regulating, used on an engine driving a pump to maintain a constant inlet or outlet pressure on the pump.

At this time on heavy-duty truck and construction equipment applications, straight mechanically designed units dominate the governor used on nonelectronic fuel injection systems.

Mechanical Governors

In most governors installed on diesel engines used by the Navy, the centrifugal force of rotating weights (flyballs) and the tensions of a helical coil spring (or springs) are used in governor operation. On this basis, most of the governors used on diesel engines are generally called mechanical centrifugal flyweight governors.

In mechanical centrifugal flyweight governors (fig. 5-6), two forces oppose each other. One of these forces is tension spring (or springs) which may be varied either by an adjusting device or by movement of the manual throttle. The engine produces the other force. Weights, attached to the governor drive shaft, are rotated, and a centrifugal force is created when the engine drives the shaft. The centrifugal force varies with the speed of the engine.

Transmitted to the fuel system through a connecting linkage, the tension of the spring (or springs) tends to increase the amount of fuel delivered to the cylinders. On the other hand, the centrifugal force of the rotating weights, through connecting linkage, tends to reduce the quantity of fuel injected. When the two opposing forces are equal, or balanced, the speed of the engine remains constant

To show how the governor works when the load increases and decreases, let us assume you are driving a truck in hilly terrain. When a truck approaches a hill at a steady engine speed, the vehicle is moving from a set state of balance in the governor assembly (weights and springs are equal) with a fixed throttle setting to an unstable condition. As the vehicle starts to move up the hill at a fixed speed, the increased load demands result in a reduction in engine speed. This upsets the state of balance that had existed in the governor. The reduced rotational speed at the engine results in a reduction in speed, and, therefore, the centrifugal force of the governor weights. When the state of balance is upset, the high-speed governor spring is allowed to expand,

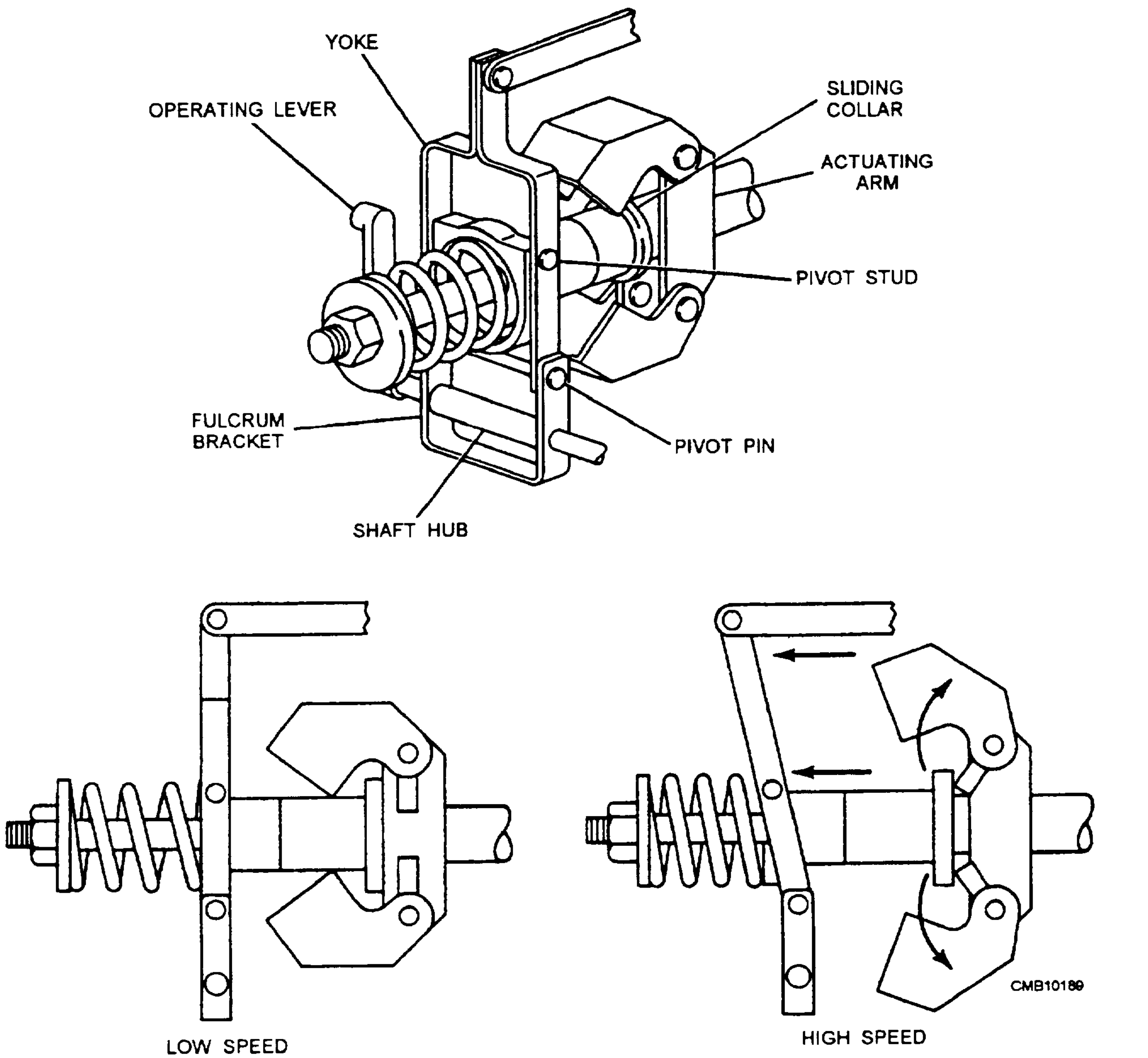


Figure 5-6.—Mechanical (centrifugal) governor.

giving up some of its stored energy, which moves the connecting fuel linkage to an increased delivery position. This additional fuel delivered to the combustion chambers would result in an increase in horsepower, but not necessarily an increase in engine speed.

When the truck moves into a downhill situation, the operator is forced to back off the throttle to reduce the speed of the vehicle; otherwise, the brakes or engine/transmission retarder has to be applied. The operator can also downshift the transmission to obtain additional braking power. However, when the operator does not reduce the throttle position or brake the vehicle mass in some way, an increase in road speed results. This is due to the reduction in engine load because of the additional reduction in vehicle resistance achieved through the mass weight of the vehicle and its load pushing the truck downhill. This action causes the governor weights to increase in speed, and they attempt to compress the high-speed spring, thereby reducing the fuel delivery to the engine. Engine overspeed can result if the road wheels of the vehicle are allowed to rotate fast enough that they, in effect, become the driving member.

The governor assembly would continue to reduce fuel supply to the engine due to increased speed of the engine. If overspeed does occur, the valves can end up floating (valve springs are unable to pull and keep the valves closed) and striking the piston crown. Therefore, it is necessary in a downhill run for the operator to ensure that the engine speed does not exceed maximum governed rpm by application of the vehicle, engine, or transmission forces.

Favorable, as well as unfavorable, characteristics are to be found in mechanical governors. Advantages are as follows:

- They are inexpensive.
- They are satisfactory when it is not necessary to maintain exactly the same speed, regardless of load.
- They are extremely simple with few parts.

Disadvantages are as follows:

- They have large deadbands, since the speed-measuring device must also furnish the force to move the engine fuel control.
- Their power is relatively small unless they are excessively large.
- They have an unavoidable speed droop, and therefore cannot truly provide constant speed when this is needed.

Hydraulic Governors

Although hydraulic governors have more moving parts and are generally more expensive than mechanical governors, they are used in many applications because they are more sensitive, have greater power to move the fuel control mechanism of the engine, and can be timed for identical speed for all loads.

In hydraulic governors (fig. 5-7), the power which moves the engine throttle does NOT come from the speed-measuring device, but instead comes from a hydraulic power piston, or servomotor. This is a piston that is acted upon by fluid pressure, generally oil under the pressure of a pump. By using appropriate piston size and oil pressure, the power of the governor at its output shaft (work capacity) can be made sufficient to operate the fuel-changing mechanism of the largest engines.

The speed-measuring device, through its speeder rod, is attached to a small cylindrical valve, called a pilot valve. The pilot valve slides up and down in a bushing, which contains ports that control the oil, flow to and from the servomotor. The force needed to slide the pilot valve is very little; a small ball head is able to control a large amount of power at the servomotor.

The basic principle of a hydraulic governor (fig. 5-7) is very simple. When the governor is operating at control speed or state of balance, the pilot valve closes the port and there is no oil flow.

When the governor speed falls due to an increase in engine load, the flyweights move in and the pilot valve

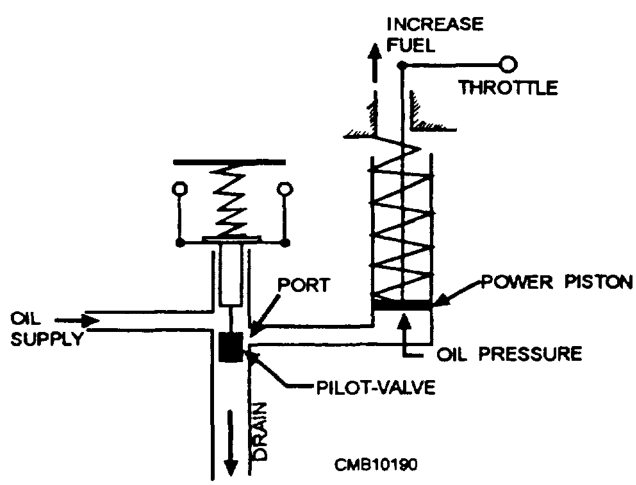


Figure 5-7.—Hydraulic governor.

moves down. This opens the port to the power piston and connects the oil supply of oil under pressure. This oil pressure acts on the power piston, forcing it upward to increase the fuel.

When the governor speed rises due to a decrease of engine load, the flyweights move out and the pilot valve moves up. This opens the port from the power piston to the drain into the sump. The spring above the power piston forces the power piston down, thus decreasing the speed.

Unfortunately, the simple hydraulic governor has a serious defect, which prevents its practical use. It is inherently unstable; that is, it keeps moving continually, making unnecessary corrective actions. In other words it hunts. The cause of this hunting is the unavoidable time lag between the moment the governor acts and the moment the engine responds. The engine cannot come back to the speed called for by the governor.

Most hydraulic governors use a speed droop to obtain stability. Speed droop gives stability because the engine throttle can take only one position for any speed. Therefore, when a load change causes a speed change, the resulting governor action ceases at a particular point that gives the amount of fuel needed for a new load. In this way speed droop prevents unnecessary governor movement and overcorrection (hunting).

Electronic Governors

The recent introduction of electronically controlled diesel fuel injection system on several heavy-duty high-speed truck engines has allowed the speed of the diesel engine to be controlled electronically, rather than mechanically. The same type of balance condition in a mechanical governor occurs in an electronic governor. The major difference is that in the electronic governor, electric currents (amperes) and voltages (pressure) are used together instead of mechanical weight and spring forces. This is possible through the use of magnetic pickup sensor (MPS), which is, in effect, a permanent-magnet single-pole device. This magnetic pickup concept is being used on all existing electronic systems and its operation can be considered common to all of them. MPS's are a vital communications link between the engine crankshaft speed and the onboard computer (ECM). The MPS is installed next to a drive shaft gear made of a material that reacts to a magnetic field. As each gear tooth passes the MPS, the gear interrupts the MPS's magnetic field. This, in turn, produces an ac current signal, which corresponds to the rpm of the engine. This signal is sent to the ECM to establish the amount of fuel that should be injected into the combustion chambers of the engine. Electronic speed governing systems are set up to provide six basic governing modes:

1. Idle speed control
2. Maximum speed control
3. Power takeoff speed control
4. Vehicle speed cruise control
5. Engine speed cruise control
6. Road speed limiting

Each of the control modes above is described in more detail below.

1. The idle speed control provides fixed speed control over the entire torque capability of the engine. Also, the idle speed set point is calculated as a function of the engine temperature to provide an optional cold idle speed, which is usually several hundred rpm higher than normal operating temperature.
2. The engine maximum rpm setting can be programmed for different settings. This can improve fuel economy by eliminating engine overspeed in all gear ranges.
3. The power takeoff speed control setting can operate at any speed between idle and maximum. The operator uses rotary control or a toggle switch in the cab to vary electronically the engine power to the PTO from idle to the preset rpm.
4. Vehicle and engine cruise control includes set, resume, and coast features similar to that of a passenger car, as well as an accelerate (ACCEL) mode to provide a fixed speed increase each time the control switch is activated.
5. The road speed limiting function allows the organization assigned to determine what maximum vehicle road speed they desire independent of the maximum governed speed setting of the engine. Road speed governing provides the best method for ensuring ideal fuel economy.

The major advantage of the electronic governor over the mechanical governor lies in its ability to modify speed reference easily by various means to control such things as acceleration and deceleration, as well as load.

DIESEL FUEL SYSTEM COMPONENTS

Before discussing the various types of fuel injection systems, let's spend some time looking at the basic components that are necessary to hold, supply, and filter the fuel before it passes to the actual injection system. The basic function of the fuel system is to provide a reservoir of diesel fuel, to provide sufficient circulation of clean filtered fuel for lubrication, cooling and combustion purposes, and to allow warm fuel from the engine to recirculate back to the tank(s). The specific layout and arrangement of the diesel fuel system will vary slightly between makes and models.

The basic fuel system consists of the fuel tank(s) and a fuel transfer pump (supply) that can be a separate engine-driven pump or can be mounted on or inside the injection pump. In addition, the system uses two fuel filters—a primary and secondary filter—to remove impurities from the fuel. In some system you will have a fuel filter/water separator that contains an internal filter and water trap.

Tank and Cap

Fuel tanks used today can be constructed from black sheet steel, or for lighter weight, aluminum alloy is used. Baffles are welded into the tanks during construction. The baffle plates are designed with holes in them to prevent the fuel from sloshing during the movement of the vehicle. The fuel lines (inlet and return) should be separated by a baffle in the tank to prevent warm return fuel from being sucked right back up by the fuel inlet line. Both the inlet and return lines should be kept 2 inches above the bottom of the tank, so sediment or water is not drawn into the inlet.

A well-designed tank will contain a drain plug in the base to allow for fuel tank drainage. This allows the fuel to be drained from the tank before removal for any service. Many tanks are equipped with a small low-mounted catchment basin so that any water in the tank can be quickly drained through a drain cock, which is surrounded by a protective cage to prevent damage.

The fuel tank filler cap is constructed with both a pressure relief valve and a vent valve. The vent valve is designed to seal when fuel enters it due to overfilling, vehicle operating angle, or sudden jolt that would cause fuel slosh within the tank. Although some fuel will tend to seep from the vent cap, this leakage should not exceed 1 ounce per minute.

The diesel fuel tank is mounted directly on the chassis of construction equipment because of its weight (when filled) and to prevent movement of the tank when the equipment is operated over rough terrain. Its location depends on the type of equipment and the use of the equipment. On equipment used for ground clearing and earthwork, the tank is mounted where it has less chance of being damaged by foreign objects or striking the ground.

Gauges

The electric gauges used in the diesel fuel system are the same types as used in the gasoline fuel system. Some manufacturers use a bayonet type gauge permanently attached to the filler cap of the fuel tank or installed under the fuel cap. These are graduated and the fuel level is checked by the same method as oil in an engine.

Fuel Filters

The purpose of any diesel fuel filter is mainly to remove foreign particles as well as water. The use of a suitable filtration system on diesel engines is a must to avoid damage to closely fitted injection pump and injector components. The components are manufactured to tolerances as little as 0.0025 mm; therefore, insufficient fuel filtration can cause serious problems. Six principal filter elements have been used for many years:

1. Pleated paper
2. Packed cotton thread
3. Wood fibers
4. Mixtures of packed cotton and wood fibers
5. Wound cotton or synthetic yarn
6. Fiber glass

Filter ability will vary between the type and manufacturer. On diesel engines a primary and secondary filter are used. The primary filter is capable of removing dirt particles down to 30 microns and the secondary filter between 10 to 12 microns. Secondary filters are available between 3 and 5 microns, which are used in severe service operations. The primary is usually located between the tank and the supply pump and the secondary filter between the supply pump and the injection pump. Diesel fuel filters are referred to as full-flow filters, because all the fuel must pass through them before reaching the injection pumps.

Some filters use an internal replaceable element inside a bowl or shell; these are commonly referred to as a shell and element design (fig. 5-8). However, most filters used today are of the spin-on type, which allows for faster change out since the complete filter is a throwaway. Fuel filter elements or cartridges should be replaced at the recommended interval designated by the manufacturer's service manual.

NOTE

Should the engine run rough after a fuel filter change, it is likely that air is trapped in the system. Bleed all air from the filter by loosening the bleed screw. In the absence of a bleed screw, individually loosen the fuel lines until all air has been vented.

Water Separators

The purpose of a fuel filter is mainly to remove foreign particles as well as water. However, too much water in a fuel filter will render it incapable of protecting the system. So to ensure this does not happen, most diesel engine fuel systems are now equipped with fuel filter/water separators for the main purpose of trapping and holding water that may be mixed in with the fuel. Generally, when a fuel filter/water separator is used on a diesel engine, it also serves as the primary filter. There are a number of manufacturers who produce fuel filter/water separators with their concept of operation being common and only design variations being the major difference. Basic operation is as follows:

- The first stage of the fuel filter/water separator uses a pleated paper element to change water particles into large enough droplets that will fall by gravity to a water sump at the bottom of the filter.
- The second stage is made of silicone-treated nylon that acts as a safety device to prevent small particles of water that avoid the first stage from passing into the engine.

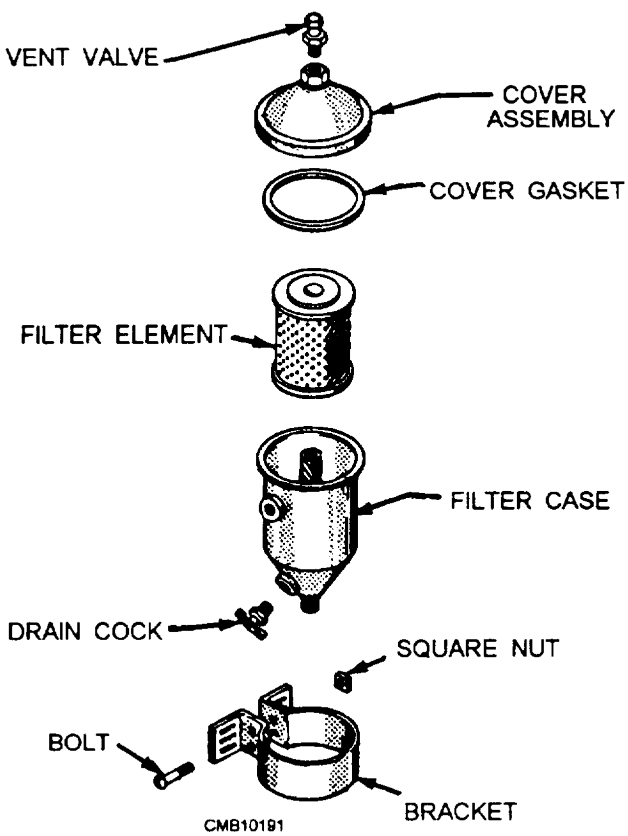


Figure 5-8.—Fuel filter assembly with replaceable element.

Supply Pump

Fuel injection pumps must be supplied with fuel under pressure because they have insufficient suction ability. All diesel injection systems require a supply pump to transfer fuel from the supply tank through the filters and lines to the injection pump. Supply pumps can be either external or internal to the injection pump. The two types of supply pumps used on diesel engines today are the gear type and the vane type.

The remaining task to be accomplished by the fuel system is to provide the proper quantity of fuel to the cylinders of the engine. This is done differently by each manufacturer and is referred to as FUEL INJECTION.

Q1. What grade of diesel fuel is used in warm and moderate climates?

Q2. What determines the lowest temperature at which diesel fuel can be pumped through the system?

Q3. What is the most important characteristic of diesel fuel?

Q4. What combustion chamber is designed principally for the use in the multifuel engine?

Q5. What term is used to indicate the zero-droop capability of a governor?

Q6. What type of governor uses a magnetic speed pickup to monitor the rpm of the engine?

Q7. What component in a hydraulic governor provides power to move the throttle of the engine?

Q8. How many governing modes does the electronic speed governing system provide?

Q9. How far should the inlet and outlet lines be from the bottom of a fuel tank?

METHODS OF INJECTION

LEARNING OBJECTIVE: *Describe the principles and operation of the different diesel fuel systems.*

You have probably heard the statement that "the fuel injection system is the actual heart of the diesel engine." When you consider that indeed a diesel could not be developed until an adequate fuel injection system was designed and produced, this statement takes on a much broader and stronger meaning.

In this section, various methods of mechanical injections and metering control are described. There have been many important developments in pumps, nozzles, and unit injectors for diesel engines over the years with the latest injection system today relying on electronic controls and sensors.

FUEL INJECTION SYSTEMS

Diesel fuel injection systems must accomplish five particular functions-meter, inject, time, atomize, and create pressure. A description of these functions follows:

1. **METER—**Accurately measure the amount of fuel to be injected.
2. **INJECT—**Force and distribute the fuel into the combustion chamber.
3. **TIME—**Injection of the fuel must start and stop at the proper time.
4. **ATOMIZE—**Break the fuel up into a fine mist.
5. **CREATE PRESSURE—**Create the necessary high pressure for injection.

You can remember these functions by the initials, **MITAC.** All five of these functions are necessary for complete and efficient combustion

Metering

Accurate metering or measuring of the fuel means that, for the same fuel control setting, the same quantity of fuel must be delivered to each cylinder for each power stroke of the engine. Only in this way can the engine operate at uniform speed with uniform power output. Smooth engine operation and an even distribution of the load between the cylinders depend upon the same volume of fuel being admitted to a particular cylinder each time it fires and upon equal volumes of fuel being delivered to all cylinders of the engine.

Injection Control

A fuel system must also control the rate of injection. The rate at which fuel is injected determines the rate of combustion. The rate of injection at the start should be low enough that excessive fuel does not accumulate in the cylinder during the initial ignition delay (before combustion begins). Injection should proceed at such a rate that the rise in combustion pressure is not to great, yet the rate of injection must be such that fuel is introduced as rapidly as possible to obtain complete combustion. An incorrect rate of injection affects engine operation in the same way as improper timing. When the rate of injection is too high, the results are similar to those caused by an injection that is too early; when the rate is too low, the results are similar to those caused by an injection that is too late.

Timing

In addition to measuring the amount of fuel injected, the system must properly time injection to ensure efficient combustion so that maximum energy can be obtained from the fuel. When the fuel is injected too early in the cycle, ignition may be delayed because the temperature of the air, at this point, is not high enough. An excessive delay, on the other hand, gives rough and noisy operation of the engine. It also permits some fuel to be lost due to the wetting of the cylinder walls and piston head. This, in turn, results in poor fuel economy, high exhaust gas temperature, and smoke in the exhaust. When fuel is injected too late in the cycle, all the fuel will not be burned until the piston has traveled well past top center. When this happens, the engine does not develop enough power, the exhaust is smoky, and fuel consumption is high.

Atomization of Fuel

As used in connection with fuel injection, atomization means the breaking up of the fuel, as it enters the cylinder into small particles, which form a mistlike spray. Atomization of the fuel must meet the requirements of the type of combustion chamber in use. Some chambers require very fine atomization; while others function with coarser atomization. Properly atomization makes it easier to start the burning process and ensures that each minute particle of fuel is surrounded by particles of oxygen with which it can combine.

Atomization is generally obtained when liquid fuel, under high pressure, passes through the small opening (or openings) in the injector or nozzle. As the fuel enters the combustion space, high velocity is developed because the pressure in the cylinder is lower than the fuel pressure. The created friction, resulting from the fuel passing through the air at high velocity, causes the fuel to break up into small particles.

Creating Pressure

A fuel injection system must increase the pressure of the fuel to overcome compression pressure and to ensure proper dispersion of the fuel injected into the combustion space. Proper dispersion is essential if the fuel is to mix thoroughly with the air and burn efficiently. While pressure is a chief contributing factor, the dispersion of the fuel is influenced, in part, by atomization and penetration of the fuel. (Penetration is the distance through which the fuel particles are carried by the motion given them, as they leave the injector or nozzle .)

If the atomization process reduces the size of the fuel particles too much, they will lack penetration. Too little penetration results in the small particles of fuel igniting before they have been properly distributed or dispersed in the combustion space. Since penetration and atomization tend to oppose each other, a compromise in the degree of each is necessary in the design of the fuel injection equipment, particularly if uniform distribution of fuel within the combustion chamber is to be obtained.

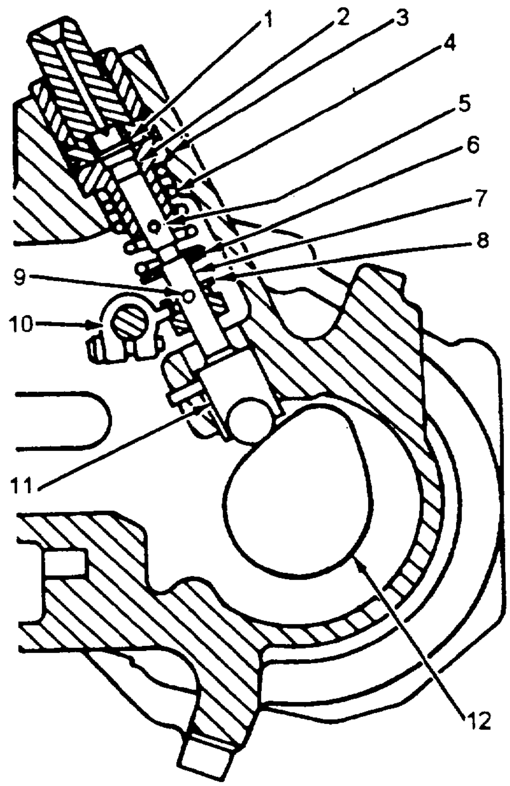
CATERPILLAR FUEL SYSTEMS

The Caterpillar diesel engine uses the pump and nozzle injection system. Each pump measures the amount of fuel to be injected into a particular cylinder, produces the pressure for injection of the fuel, and times the exact point of injection. The injection pump plunger is lifted by cam action and returned by spring action. The turning of the plungers in the barrels varies the metering of fuel. These plungers are turned by governor action through a rack that meshes with the gear segments on the bottom of the pump plungers. Each pump is interchangeable with other injection pumps mounted on the pump housing.

The sleeve metering and scroll-type pumps that are used by Caterpillar operate on the same fundamentals—a jerk pump system (where one small pump contained in its own housing supplied fuel to one cylinder). Individual "jerk" pumps, that are contained in a single injection pump housing with the same number of pumping plungers being the same as that of the engine cylinders, are commonly referred to as in-line multiple-plunger pumps.

Sleeve Metering Fuel System

The sleeve metering fuel system (fig. 5-9) was designed to have the following seven advantages:



1. Reverse flow check valve
2. Chamber
3. Barrel
4. Spring
5. Fuel inlet
6. Retainer
7. Plunger
8. Sleeve
9. Fuel outlet
10. Sleeve control lever
11. Lifter
12. Camshaft

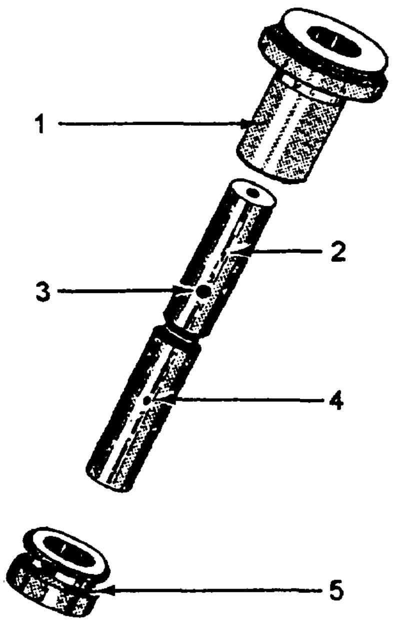
CMB10192

Figure 5-9.—Sleeve metering fuel pump assembly.

1. To have fewer moving parts and fewer total parts.
2. Simple design with compactness.
3. It can use a simple mechanical governor. No hydraulic assist required.
4. The injection pump housing is filled with fuel oil, rather than crankcase oil for lubrication of all internal parts.
5. The plunger, barrel, and sleeve design used in all Caterpillar sleeve metering units follows a common style.
6. The transfer pump, governor, and injection pump are mounted in one unit.
7. Uses a centrifugal timing advance for better fuel economy and easier starts.

The term *sleeve metering* comes from the method used to meter the amount of fuel sent to the cylinders—a sleeve system (fig. 5-10). Rather than rotate the plungers to control the amount of fuel to be injected, like most pump and nozzle injection systems, the use of a sleeve is incorporated with the plunger. The sleeve blocks a spill port that is drilled into the plunger. The amount of plunger travel with its port blocked determines the amount of fuel to be injected. Basic operation is as follows:

- Fuel is drawn from the fuel tank by the transfer pump through the fuel/water separator and the primary and secondary filters.
- Fuel from the transfer pump fills the injection pump housing at approximately 30 to 35 psi with the engine operating under full load. Any pressure in excess of this will be directed back to the inlet side of the transfer pump by the bypass valve. A constant-bleed valve is also used to allow a continuous return of fuel back to the tank at a rate of approximately 9 gallons per hour, so the temperature of the fuel stays cool for lubrication purposes and assist in maintaining housing pressure.
- Since the injection pump is constantly filled with diesel from the transfer pump under pressure, any time the fill port is uncovered, the internal drilling of the plunger will be primed by the incoming fuel caused by the downward moving plunger relative to pump camshaft rotation (fig. 5-11).
- At the correct moment, the rotation of the pump cam lobe begins to force the plunger upward until the fill port is closed, as it passes into the barrel. At the same time the sleeve closes the spill port. The pump, line, and fuel valves are subjected to a buildup in fuel pressure and injection will begin (fig. 5-11).



1. Barrel
2. Plunger
3. Fill port
4. Spill port
5. Metering sleeve

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Figure 5-10.—Sleeve metering barrel and plunger assembly.

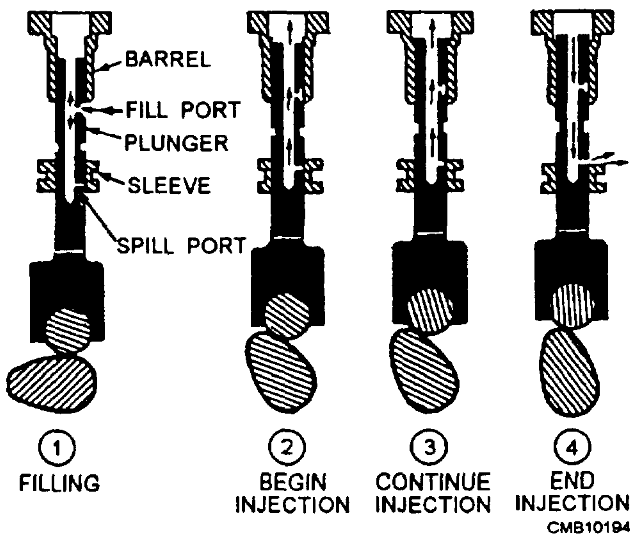


Figure 5-11.—Injection pump operating cycle.

- Injection of the fuel will continue as long as both the fill port and spill ports are completely cover by the barrel and sleeve (fig. 5-11).
- Injection ends the moment that the spill port starts to edge above the sleeve, releasing the pressure in the plunger and letting fuel escape from the pump back into the housing. Also, at the end of the stroke, the check valve closes to prevent the fuel from flowing back from the injector fuel line (fig. 5-11).

To increase the amount of fuel injected, raise the sleeve through the control shaft and fork so that the sleeve is effectively positioned higher up on the plunger. This means that the spill port will be closed for a longer period of time, as the cam lobe is raising the plunger. Increasing the effective stroke of the plunger (time that both ports are closed) will increase the amount of fuel delivered.

NOTE

For procedures on removing, replacing, and servicing the injection pumps in a sleeve metering fuel system, refer to the manufacturer's service manual.

GOVERNOR ACTION.—The governor on a Caterpillar sleeve metering fuel system is a mechanical governor and acts throughout the entire speed range of the engine. The majority of the sleeve metering fuel system uses three springs-a low-idle (inner) spring, a high-idle (outer) spring, and a dashpot spring. When the operator requires more power from the engine, he/she steps on the throttle. This causes the governor control lever to apply pressure that compresses the governor spring and to transfer this motion to the thrust collar. Since governor action from the spring and weight motion is of the back and forth variety, an additional linkage between the injection pumps and the governor transforms this sliding horizontal governor movement from the thrust collar into a rolling motion at the sleeve control shaft. A simple connecting lever commonly known as a bell crank lever accomplishes this action.

The bell crank lever contacts the thrust collar on one end and the governor sleeve control shaft on the other end. The bell crank pivots on a fixed vertical bell crankshaft to gain mechanical advantage through the lever principle. At the sleeve shaft end, it rides in a ball-and-socket joint that holds it in place and minimizes linkage movement. Therefore, any horizontal movement at the governor weight shaft and spring will cause an equally precise movement at the ball-and-socket joint, leading to reposition of the sleeves. If, in this case, the operator has increased the throttle position, the sleeves would be lifted, thereby covering the spill port for a longer overall effective plunger stroke.

As with any mechanical governor, an increase in either the throttle position or load will cause a speed change to the engine. Spring pressure is always trying to increase the fuel delivered to the engine, while centrifugal force of the rotating weights is always trying to decrease the amount of fuel going to the engine. Somewhere within the throttle range, however, a state of balance between these two opposing forces will exist as long as the engine speed is capable of overcoming the load placed on it to keep the spring and weight force in a state of balance.

When the engine is stopped, the action of the governor spring force places the thrust collar and the sleeve control shaft to the full-fuel position; therefore, easier starting is accomplished Once the operator cranks and starts the engine, centrifugal force will cause the flyweights to move outward, which now opposes the spring force, and the thrust collar and spring seat will come together, as they are pushed to a decreased fuel position. When the force of the weights equals the preset force of the spring established by the idle adjusting screw, these forces will be in a state of balance, and the engine will run at a steady idle speed with the throttle at a normal idle position.

Governor action will operate from idle throughout the speed range of the engine. A load stop pin controls the maximum speed of the engine. Rotation of the throttle lever causes the load stop lever to lift the load stop pin until it comes in contact with the stop bar or screw, thereby limiting any more fuel to the engine.

The purpose of the dashpot governor spring is to prevent any surging or irregular speed regulation of the engine by the fact that the piston either pulls fuel into or pushes fuel out of its cylinder through an orifice. The dashpot governor spring force varies with the piston movement, and as the engine load is increased or decreased, fuel is drawn into the piston cylinder through the orifice. This action gives the effect of a high governor spring rate that minimizes speed variations through oscillation during load changes of the engine. At any time the ignition switch is turned off or the governor speed control lever is moved to the OFF position, the sleeve levers move the sleeves down, cutting off fuel to the cylinders.

> **NOTE**
>
> Any and all adjustments to the governor and governor controls should be made according to the manufacturer's manual and specifications.

AUTOMATIC TIMING ADVANCE UNIT.— All current Caterpillar engines use some form of automatic timing for the fuel injection pump. On sleeve metering injection systems, this advance is mounted on the front end of the camshaft of the engine. The gear of the automatic advance unit meshes with and drives the fuel injection pump camshaft. The principal parts of the advance unit are the slides, the springs, and the weights. Operation of the automatic advance-timing unit is as follows:

- The slides are located and driven by two dowels, attached to the engine camshaft gear. 'The slides, in turn, fit into notches within the weights, thereby transferring their drive from the engine camshaft gear to the weights.
- With the engine running, centrifugal force exerted by the rotating weight assemblies cause them to act against the force of the springs.
- Since the weights are designed with notches in them, as they move outward under centrifugal force, they cause the slides to effect a change in the angle between the timing advance gear and the two drive dowels of the engine camshaft.
- This relative movement of the timing advance unit gear will, therefore, automatically advance or retard the timing of the fuel injection pump in relation to the engine speed and load.

However, built into the advance unit is a maximum timing variation of 5 degrees with the timing change starting at approximately low idle rpm and continuing on up to the rated speed of the engine; therefore, you cannot adjust the automatic timing advance unit. The timing unit is lubricated by engine oil under pressure from drilled holes at the engine camshaft front bearing.

Scroll Metering Fuel System

The scroll metering fuel system is similar to the sleeve metering fuel system in that it uses a plunger and barrel to create high pressure for injection. This system was designed to create higher injection pressure on direct-injection engines, offering an approximate 10 percent fuel economy improvement over precombustion-type engines, along with the ability to meet long-term EPA exhaust emissions regulations and better overall engine performance, as well as the ability to provide greater part commonality between different series engines.

In a scroll system two helix cut ports are used—the bypass closed port and the spill port Fuel is supplied from the transfer pump to an internal fuel manifold in the injection pump housing at approximately 35 psi. When the pump plunger is at the bottom of its stroke, fuel at transfer pump pressure flows around the pump barrel and to both the bypass closed port and spill port, which are both open at this time to allow fuel to flow into the barrel area above the plunger. The pump plunger is moved up and down by the action of a roller lifter, riding on the injection pump camshaft, which rotates at one-half of engine speed. As the injection pump camshaft rotates and the plungers rises, some fuel will be pushed back out of the bypass closed port until the top of the plunger eventually closes both the bypass closed port and the spill port. Further plunger movement will cause an increase in the trapped fuel pressure, and at approximately 100 psi, a check valve will open and fuel will flow into the injection line to the injection nozzle.

The fuel pressure of 100 psi is not enough to open the injection nozzle, which has an opening pressure of between 1,200 and 2,350 psi for a 3300 series engine and between 2,400 and 3,100 psi on 3406 engines. However, as the plunger continues to move up in its barrel, this fuel pressure is reached very quickly.

A high-pressure bleed-back passage and groove machined around the barrel are in alignment during the effective stroke to bleed off any fuel that leaks between the plunger and the barrel for lubrication purposes.

When the upward moving plunger uncovers the spill port, injection ceases, and although the plunger can still travel up some more, this is simply to allow most of the warm fuel (due to being pressurized) to spill back into the manifold. As the plunger moves downward in the barrel, it will once again uncover the bypass closed port and cool fuel will fill the area above the plunger for the next injection. When the spill port is opened, pressure inside the barrel is released and the check valve is seated by its spring.

Within the check valve assembly is a reverse flow check valve that opens when fuel pressure in the injection line remains above 1,000 psi and closes as soon as the fuel pressure drops to 1,000 psi. This will keep the fuel lines filled with fuel at 1,000 psi and ready for the next injection. This provides for a consistent and smooth engine power curve.

TRANSFER PUMP.—With the introduction of the scroll metering fuel system, the gear-type fuel transfer pump that had been used for years by Caterpillar was superseded by the use of a piston-type transfer pump. Current scroll metering fuel systems use a single-piston, double-acting pump with three one-way check valves.

The transfer pump is bolted to the low side of the injection pump housing. It is capable of delivering up to 51 gallons of fuel per hour at 25 psi. There is no need for a relief valve in this transfer pump due to the fact that maximum pressure is controlled automatically by the force of the piston return spring.

The transfer pump is activated by an eccentric (a device that converts rotary motion into reciprocating motion) on the injection pump camshaft, causing the pushrod to move in and out, as the engine is running. This action causes the piston to move down against the force of the piston return spring inside the transfer pump housing. The downward movement of the piston will cause the inlet check valve and the outlet check valve to close, while allowing the pumping check valve to open to allow fuel below the piston to flow into the area immediately above the downward piston.

As the injection pump camshaft eccentric rotates around to its low point, the transfer pump spring pushes the piston up inside its bore, causing the pumping check valve to close, and both the out and inlet valves are forced open. Fuel above the piston will be forced through the outlet check valve and the pump outlet port at approximately 35 psi. As this occurs, fuel will also flow through the pump inlet port and the inlet check valve to fill the area below the piston and the pump will repeat the cycle.

GOVERNOR.—The governor assembly used with the scroll metering fuel system is a hydra-mechanical servo-type unit. The reason for using a servo-valve is to provide a "boost" to the governor. Without the servo-valve, both the governor spring and flyweights would have to be very large and heavy. With the use of the servo assist, little force is required to move both the accelerator and the governor control lever. Basically, the governor assembly consists of three separate components:

1. The mechanical components of the governor, such as the weights, springs, and linkage.
2. The governor servo that provides hydraulic assistance through the use of pressurized engine oil to provide rapid throttle response and to reduce overall size requirement of the flyweights and springs.
3. The dashpot assembly that is designed to provide stability to the governor during rapid load/throttle changes.

FUEL INJECTOR NOZZLE.—The fuel injector nozzle, used with the scroll metering fuel system, is a multiple-hole design, inward-opening, non-leakoff type. There are minor changes between the earlier nozzles and current models. Older nozzles are identified by the use of a color-coded black or blue washer, while the newer ones use a copper washer.

The nozzle is a multiple-hole design since it is used in direct injection engines only. The number and size of the holes will vary between different series of engines. For example, the 3306 engine nozzle uses a nine-hole tip, while the nozzle in the 3406 uses a six-hole tip. These different nozzles cannot be intermixed in the same engine or switched from one series engine to another.

The nozzle is designed for injection pressures of 15,000 psi and short injection duration to prevent a loss in fuel economy due to stringent EPA emission requirements. The nozzle incorporates a carbon dam on the lower end of the pencil part of the body and a seal washer on the upper end. The carbon dam prevents carbon blow-by into the nozzle bore in the cylinder head, while the upper seal prevents compression leakage from the cylinder. Injector nozzle operation is as follows:

- The nozzle receives high-pressure fuel from the fuel pump through the inlet passage and filter screen and into the fuel passage.
- When fuel pressure is high enough, the injector valve is lifted against the force of the return spring and fuel is injected through the multiple holes in the spray tip. This causes an increase in fuel pressure and the fuel to be finely atomized spray for penetration of the compressed air in the combustion chamber.

- When fuel pressure drops below injection pressure, the return spring closes the fuel valve.

> **NOTE**
>
> For information on the removal and repair of the fuel injector nozzle, consult the manufacturer’s service manual.

DISTRIBUTOR-TYPE FUEL SYSTEMS

The distributor-type fuel system is found on small- to medium-sized diesel engines. Its operation is similar to an ignition distributor found on gasoline engine. A rotating member, called a rotor, within the pump distributes fuel at high pressure to the individual injectors in engine firing-order sequence.

There are several manufacturers of distributor-type fuel injection systems. Operation of the fuel distribution is similar, in that a central rotating member forms the pumping and the distributing rotor is driven from the main drive shaft on which the governor is mounted.

The distributor-type fuel system that will be discussed is the DB2 Roosa Master diesel fuel-injection pump, manufactured by Stanadyne's Hartford Division.

Injection Pump

The Roosa Master fuel injection pump is described as an opposed plunger, inlet metering, distributor-type pump. Simplicity, the prime advantage of this design, contributes to greater ease of service, low maintenance cost, and greater dependability. Before describing the injection pump components and operation, let’s familiarize ourselves with the model numbering system. For example, model number DB2833JN3000 breaks down like this:

D—Pump series

B—Rotor

2—Generation

8—Number of cylinders

33—Abbreviation of plunger diameter; 33, 0.330 in.

JN—Accessory code that relates to special pump options

3000—Specification number

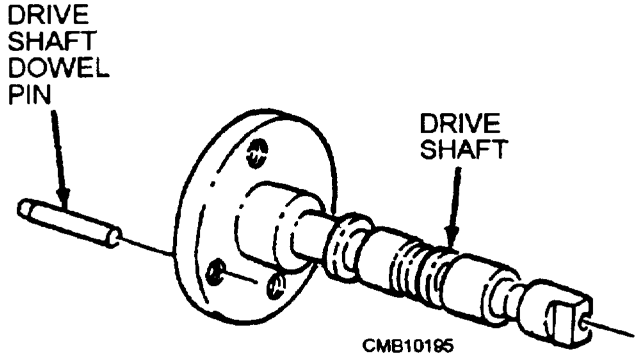


Figure 5-12.—Drive shaft.

> **NOTE**
>
> For information on the accessory code and the specification number for a particular pump, always refer to the manufacturer’s service manual.

The main components of the DB2 fuel injection pump are the drive shaft, distributor rotor, transfer pump, pumping plungers, internal cam ring, hydraulic head, end plate, governor, and housing assembly with an integral advance mechanism. The rotating members that revolve on a common axis include the drive shaft, distributor rotor, and transfer pump.

DRIVE SHAFT (fig. 5-12)—The drive shaft is the driving member that rotates inside a pilot tube pressed into the housing. The rear of the shaft engages the front of the distributor rotor and turns the rotor shaft. Two lip type seals prevent the entrance of engine oil into the pump and retain fuel used for pump lubrication.

DISTRIBUTOR ROTOR (fig. 5-13)—The distributor rotor is the drive end of the rotor, containing

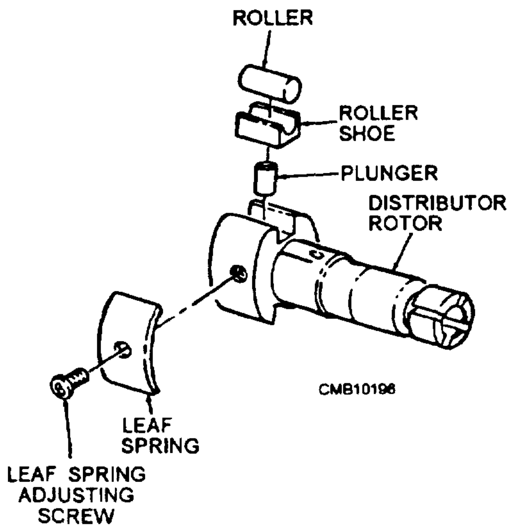
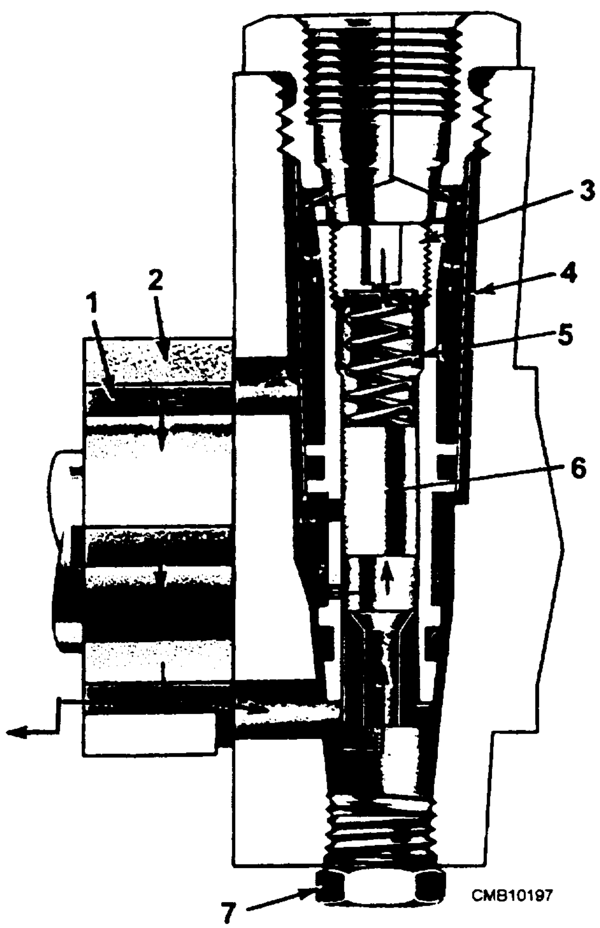


Figure 5-13.—Distributor rotor.

two pumping plungers located in the pumping cylinder. Slots in the rear of the rotor provide a place for two spring-loaded transfer pump blades. In the rotor, the shoe, which provides a large bearing surface for the roller, is carried in guide slots. The rotor shaft rotates with a very close fit in the hydraulic head. A passage through the center of the rotor shaft connects the pumping cylinder with one charging port and one discharging port The hydraulic head in which the rotor turns has a number of charging and discharging port, based on the number of engine cylinders. An eight-cylinder engine will have eight charging and eight discharging ports. The governor weight retainer is supported on the forwarded end of the rotor.

TRANSFER PUMP (fig. 5-14)—The transfer pump is a positive displacement, vane-style unit, consisting of a stationary liner with spring-loaded blades that ride in slots at the end of the rotor shaft. The delivery capacity of the transfer pump is capable of exceeding both pressure and volume requirements of the engine, with both varying in proportion to engine speed. A pressure regulator valve in the pump end plate controls fuel pressure. A large percentage of the fuel from the pump is bypassed through the regulating valve to the inlet side of the pump. The quantity and pressure of the fuel bypassed increases, as pump speed increases.



1. Transfer pump blade.
2. Transfer pump liner.
3. End plate adjusting plug.
4. Inlet strainer.
5. Regulating spring.
6. Regulating piston.
7. End plate plug.

Figure 5-14.—Transfer pump.

The operation of the model DB2 injection is similar to that of an ignition distributor. However, instead of the ignition rotor distributing high-voltage sparks to each cylinder in firing order, the DB2 pump distributes pressurized diesel fuel as two passages align during the rotation of the pump rotor, also in firing order. The basic fuel flow is as follows:

- Fuel is drawn from the fuel tank by a fuel lift pump (mechanical or electrical) through the primary and secondary filters before entering the transfer pump.
- As fuel enters the transfer pump, it passes through a cone-type filter and on into the hydraulic head assembly of the injection pump.
- Fuel under pressure is also directed against a pressure regulator assembly, where it is bypassed back to the suction side should the pressure exceed that of the regulator spring.
- Fuel under transfer pump pressure is also directed to and through a ball-check valve assembly and against an automatic advance piston.
- Pressurized fuel is also routed from the hydraulic head to a vent passage leading to the governor linkage area, allowing any air and a small quantity of fuel to return to the fuel tank through a return line which self-bleeds air from the system. Fuel that passes into the governor linkage compartment is sufficient to fill it and lubricate the internal parts.
- Fuel leaving the hydraulic head is directed to the metering valve, which is controlled by the operator throttle position and governor ‘action. This valve controls the amount of fuel that will be allowed to flow on into the charging ring and ports.

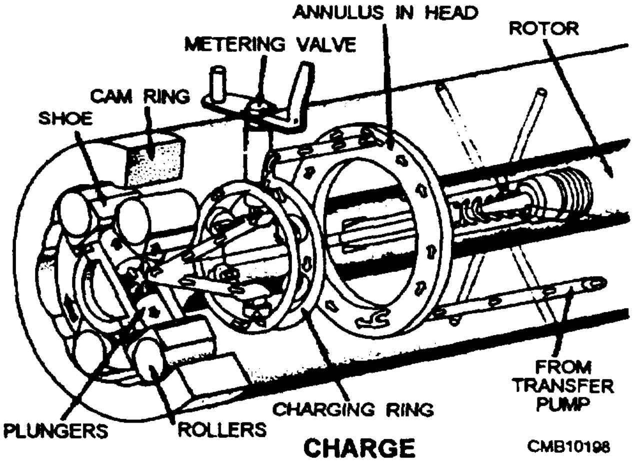


Figure 5-15.—Rotor in charge position.

- Rotation of the rotor by the drive shaft of the pump aligns the two inlet passages of the rotor with the charging ports in the charging ring, thereby allowing fuel to flow into the pumping chamber (fig. 5-15).
- The pumping chambers consists of a circular cam ring, two roller, and two plungers. As the rotor continues to turn, the inlet passages of the rotor will move away from the charging ports, allowing fuel to be discharged, as the rotor registers with one of the hydraulic head outlets.
- With the discharge port open (fig. 5-16), both rollers come in contact with the cam ring lobes, which forces them toward each other. This causes the plungers to pressurize the fuel between them and sending it on up to the injection nozzle and into the combustion chamber. The cam is relieved to allow a slight outward movement of the roller before the discharge port is closed off. This action drops the pressure in the injection line enough to give sharp cutoff injection and to prevent nozzle dribbling.

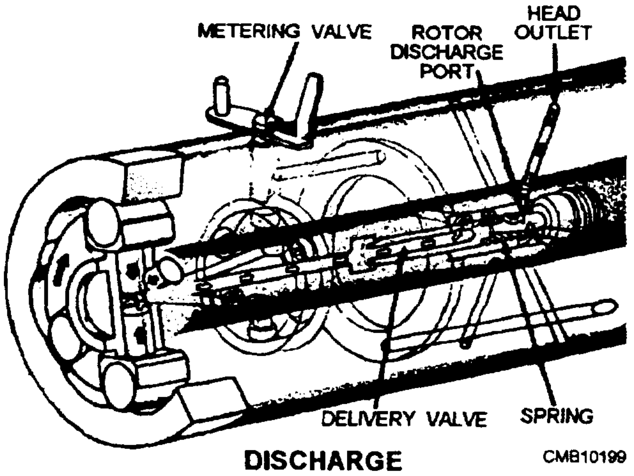


Figure 5-16.—Rotor in discharge position.

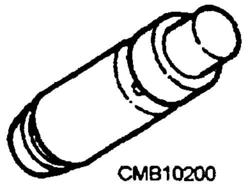


Figure 5-17.—Delivery valve.

The maximum amount of fuel that can be injected is limited by maximum outward travel of the plungers. The roller shoes, contacting an adjustable leaf spring, limit this maximum plunger travel. At the time the charging ports are in register, the rollers are between the cam lobes; therefore, their outward movement is unrestricted during the charging cycle except as limited by the leaf spring.

To prevent after-dribble and therefore unburnt fuel at the exhaust, the end of injection must occur crisply and rapidly. To ensure that the nozzle valve does, in fact, return to its seat as rapidly as possible, the **DELIVERY VALVE** (fig. 5-17). located in the drive passage of the rotor, acts to reduce injection line pressure. This occurs after fuel injection and the pressure is reduced to a value lower than that of the injector nozzle closing pressure. The valve remains closed during charging and opens under high pressure, as the plungers are forced together. Two small grooves are located on either side of the charging port or the rotor near its flange end. These grooves carry fuel from the hydraulic head charging posts to the housing. This fuel flow lubricates the cam, the rollers, and the governor parts. The fuel flows through the entire pump housing, absorbs heat, and is allowed to return to the supply tank through a fuel return line connected to the pump housing cover, thereby providing for pump cooling.

In the DB2 fuel pump, automatic advance is accomplished in the pump by fuel pressure acting against a piston, which causes rotation of the cam ring, thereby aligning the fuel passages in the pump sooner (fig. 5-18). The rising fuel pressure from the transfer pump increases the flow to the power side of the advance piston. This flow from the transfer pump passes through a cut on the metering valve, through a passage in the hydraulic head, and then by the check valve in the drilled bottom head locking screw. The check valve provides a hydraulic lock, preventing the cam from retarding during injection. Fuel is directed by a passage in the advance housing and plug to the pressure side of the advance piston. The piston moves the cam counterclockwise (opposite to the direction of the pump rotation). The spring-loaded side of the piston balances the force of the power side of the piston and limits the maximum movement of the cam. Therefore, with increasing speed, the cam is advanced and, with decreasing speed, it is retarded.

We know that a small amount of fuel under pressure is vented into the governor linkage compartment. Flow into this area is controlled by a small vent wire that controls the volume of fuel returning to the fuel tank, thereby avoiding any undue fuel pressure loss. The vent passage is located behind the metering valve bore and leads to the governor compartment by a short vertical passage. The vent wire assembly is available in several sizes to control the amount of vented fuel being returned to the tank. The vent wire should **NOT** be tampered with, as it can be altered only by removing the governor cover. The correct wire size would be installed when the pump assembly is being flow-tested on a pump calibration stand.

NOTE

For information concerning removal, installation, and servicing the injection pump, always refer to the manufacturer's service manual.

Injection Pump Accessories

The DB2 injection pump can be used on a variety of applications; therefore, it is available with several options as required. The options are as follows:

- The **flexible governor drive** is a retaining ring that serves as a cushion between the governor weight retainer and the weight retainer hub. Any torsional vibrations that may be transmitted to the pump area are absorbed in the flexible ring, therefore reducing wear of pump parts and allowing more positive governor control.

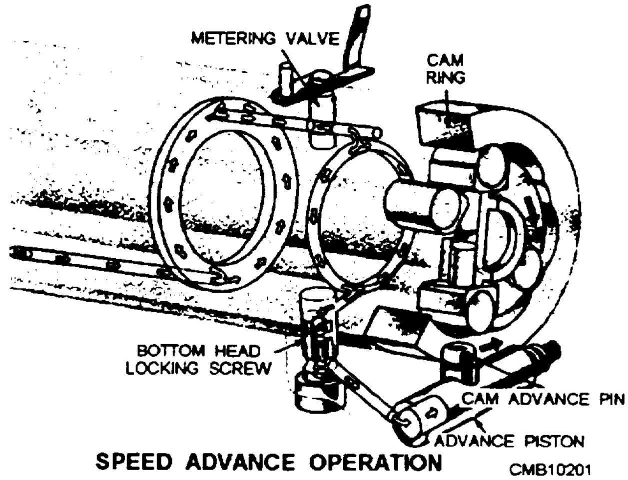


Figure 5-18.—Speed advance operation.

- The **electrical shutoff** (fig. 5-19) is available as either an energized to run (ETR) or energized to shut off (ETSO) model. In either case it will control the run and stop functions of the engine by positively stopping fuel flow to the pump plungers, thereby preventing fuel injection.
- The **torque screw,** used on DB2 pumps, allows a tailored maximum torque curve for a particular engine application. This feature is commonly referred to as torque backup, since the engine torque will generally increase toward the preselected and adjusted point as engine rpm decreases. The three factors that affect this torque are the metering valve opening area, the time allowed for fuel charging, and the transfer pump pressure curve.

Turning in the torque screw moves the fuel-metering valve toward its closed position. The torque screw controls the amount of fuel delivered at full-load governor speed.

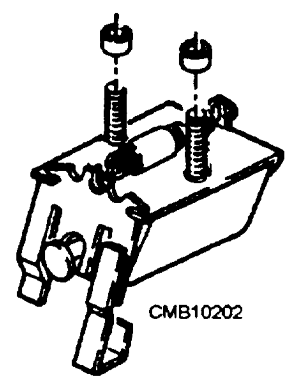


Figure 5-19.—Electrical shutoff.

If additional load is applied to the engine while it is running at full-load governed speed, there will be a reduction in engine rpm. A greater quantity of fuel is allowed to pass into the pumping chamber because of the increased time that the charging ports are open. Fuel delivery will continue to increase until the rpm drop to the engine manufacturer's predetermined point of maximum torque.

NOTE

Do **NOT** attempt to adjust the torque curve on the engine at any time. This adjustment can be done only during a dynamometer test where fuel flow can be checked along with the measured engine torque curve or on a fuel pump test stand.

Governor

The DB2 fuel injection pump uses a mechanical type governor (fig. 5-20). The governor function is that of controlling the engine speed under various load settings. As with any mechanical governor, it operates on the principle of spring pressure opposed by weight force, with the spring attempting to force the linkage to an increased fuel position at all times. The centrifugal force of the rotating flyweights attempts to pull the linkage to a decreased fuel position.

Rotation of the governor linkage varies the valve opening, thereby limiting and controlling the quantity of fuel that can be directed to the fuel plungers. The position of the throttle lever controlled by the operator's foot will vary the tension of the governor spring. This force, acting on the linkage, rotates the metering valve to an increased or decreased fuel position as required.

At any given throttle position the centrifugal force of the rotating flyweights will exert force back through the governor linkage which is equal to that of the spring, resulting in a state of balance. Outward movement of the weights acting through the governor thrust sleeve can turn the fuel-metering valve by means of the governor linkage arm and hook. The throttle and governor spring position will turn the metering valve in the opposite direction.

The governor is lubricated by fuel received from the fuel housing. Fuel pressure in the governor housing is

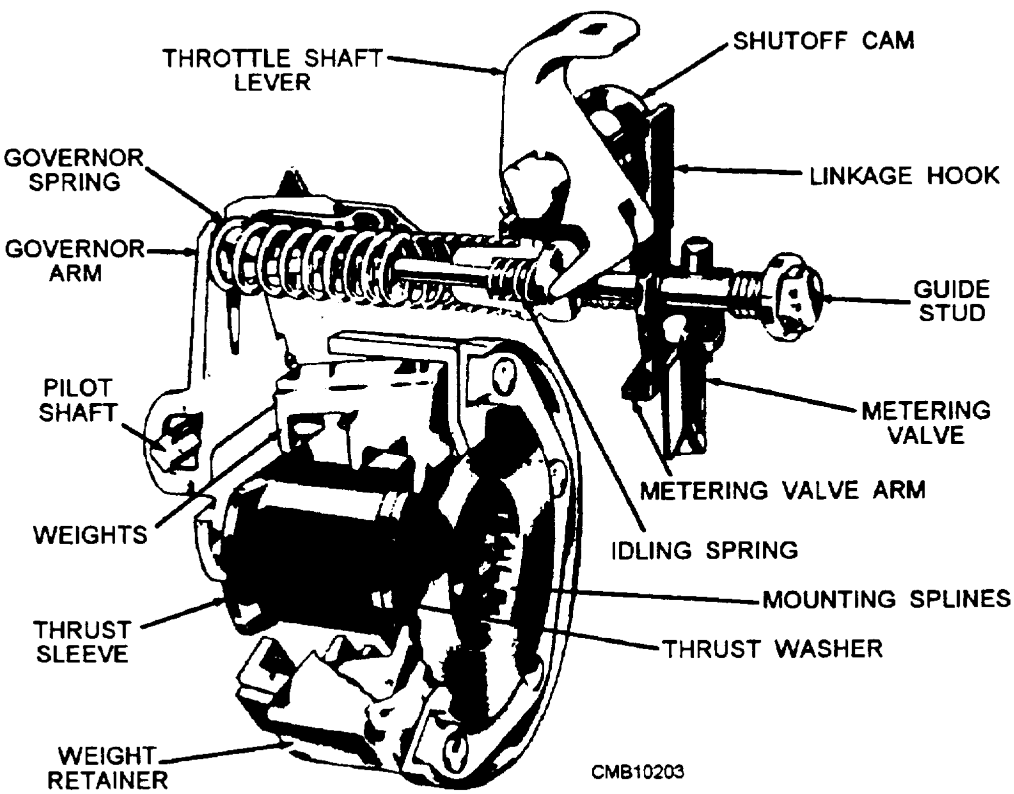


Figure 5-20.—Governor assembly.

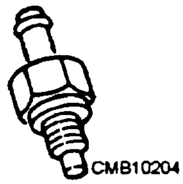


Figure 5-21.—Spring-loaded ball-check valve.

maintained by a spring-loaded ball-check return fitting (fig. 5-21) in the governor cover of the pump.

Nozzle

The injector nozzle, used with the DB2 fuel injection pump, is opened outward by high fuel pressure and closed by spring tension (fig. 5-22). It has a unique feature in that it is screwed directly into the cylinder head An outward opening valve creates a narrow spray that is evenly distributed into the precombustion chamber. Both engine compression and combustion pressure forces assist the nozzle spring in closing an outward opening valve. These factors allow the opening pressure settings of the nozzle to be lower than those of conventional injectors.

During injection, a degree of swirl is imparted to the fuel before it actually emerges around the head of the nozzle. This forms a closely controlled annular orifice with the nozzle valve seat, which produces a high-velocity atomized fuel spray, forming a narrow cone suitable for efficient burning of the fuel in the precombustion chamber.

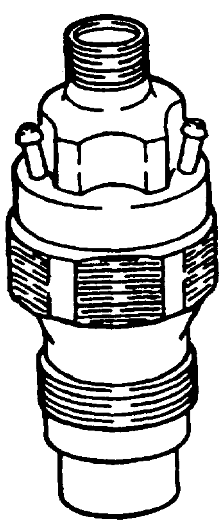


Figure 5-22.—Injector nozzle.

The nozzle has been designed as basically a throwaway item. After a period of service, the functional performance may not meet test specifications. Nozzle testing is comprised of the following checks:

- Nozzle opening pressure
- Leakage
- Chatter
- Spray pattern

Each test is done independently of the others (for example, when checking the opening pressure, do not check for leakage). If all the tests are satisfied, the nozzle can be reused. If any one of the tests is not satisfied, replace the nozzle. For testing procedures, consult the manufacturer's service manual.

CAUTION

When testing nozzles, do not place your hand or arms near the top of the nozzle. The high-pressure atomized fuel spray from the nozzle has sufficient penetrating power to puncture flesh and destroy tissue and may result in blood poisoning. The nozzle tip should always be enclosed in a receptacle, preferably transparent, to contain the spray.

DETROIT DIESEL UNIT INJECTION SYSTEMS

The fuel system used by Detroit diesel is known as a low-pressure fuel system, owing to the fact that fuel delivered to the unit injectors averages 45 to 70 psi. This is much lower than the average 2,500 to 300 psi that passes through the fuel line from the injection pump and nozzles used in other systems.

The four main functions of the fuel system used with a Detroit diesel engine are as follows:

1. To supply clean, cool fuel to the system by passing it through at least a primary and secondary filter before the pump and injectors.
2. To cool and lubricate the injectors, as the fuel flows through them, and return to the tank (recirculatory system).
3. To maintain sufficient pressure at all times through the action of the positive displacement

gear pump and the use of a restricted fitting located at the cylinder head return fuel manifold.

4. To purge the fuel system of any air; the system is recirculator-y in operation, therefore allowing any air to be returned to the fuel tank.

Since the basic fuel system used on all Detroit diesel engines is identical as far as components used, the description of operation for one can be readily related to any other series of Detroit diesel engine (fig. 5-23).

The basic fuel system consists mainly of the following:

1. Fuel injectors.
2. Fuel pipes to and from the injectors (inlet and outlet).
3. Fuel manifolds, which are cast internally within the cylinder head. The upper manifold is the "inlet" and the lower is the "return" or "outlet." To prevent confusion, the words *in* and *out* are cast in the side of the head.

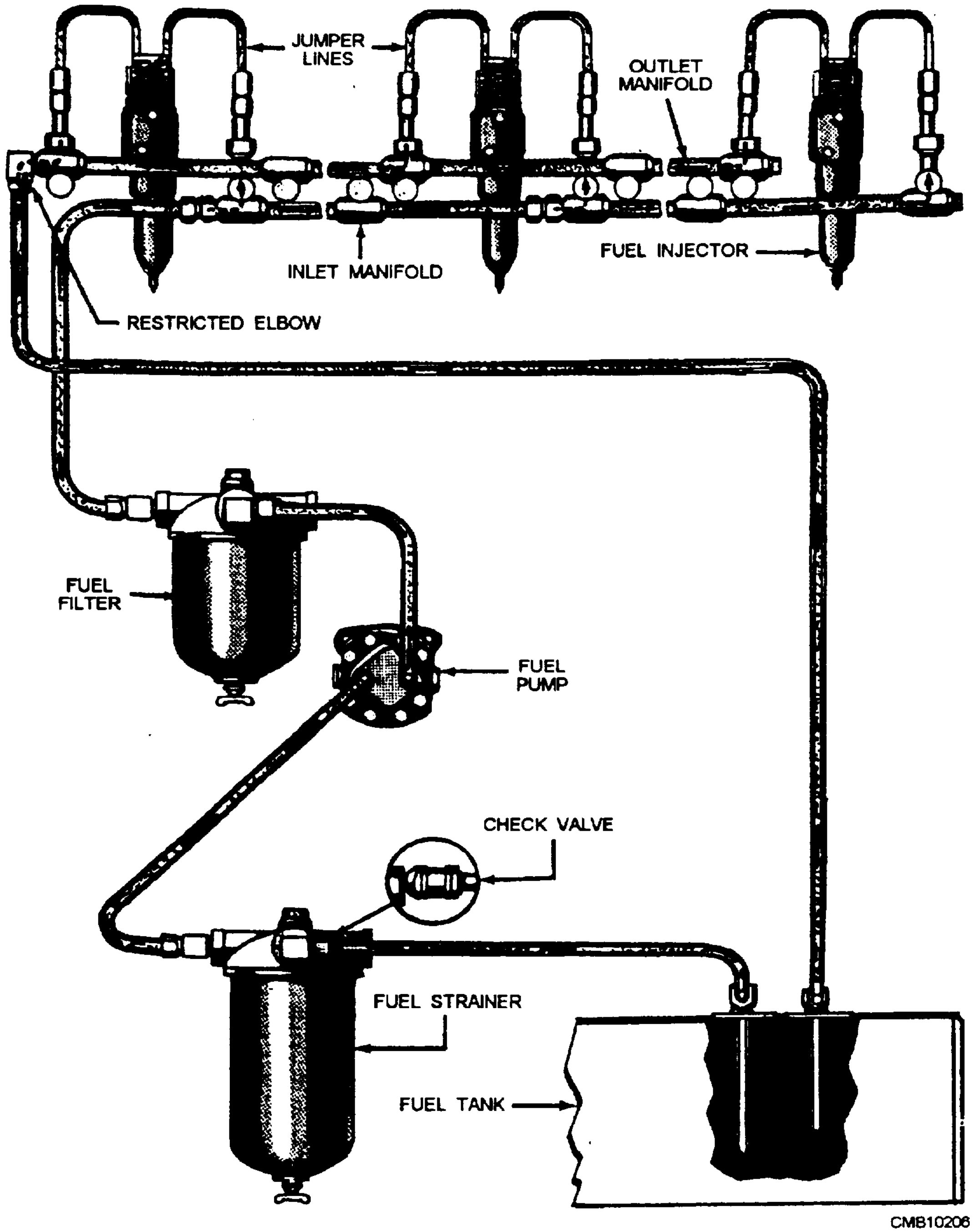


Figure 5-23.—Diagram of typical Detroit diesel fuel system.

4. Fuel pump (supply pump, not an injection pump).
5. Fuel strainer or primary filter.
6. Fuel filter (secondary).
7. Fuel lines.
8. One-way check valve.
9. Restricted fitting on in-line engines or a restricted TEE on V-type engines.

Fuel Pump

The fuel pump is a positive displacement gear-type unit that transfers fuel from the tank to the injectors at 65 to 75 psi (fig. 5-24). The standard pump has the ability to deliver 1.5 gallons per minute, or 90 gallons per hour.

The fuel pump body and cover are aligned by means of two dowels. The body and cover are machined surfaces that contain no gasket between them, although a thin coat of sealant applied to these surfaces is recommended at installation. A relief valve bypasses fuel back to the inlet side of the pump when pressure reaches above the 65 to 75 psi.

There are two oil seals pressed into the pump bore from the flanged end for the following purposes:

1. The seal closest to the drive coupling prevents lube oil from entering the fuel pump.
2. The inner seal closest to the pump gears prevents fuel leakage.

The installed seals do not butt up against each other, but have a small space between them. Drilled and taped into this cavity in the fuel pump body are two small holes—one which is usually plugged and the other one is open to allow any fuel or lube oil to drain, thereby indicating damaged seals. Sometimes a small fitting and tube extend from one of these holes to direct any leakage to a noticeable spot. Acceptable leakage should not exceed 1 drop per minute.

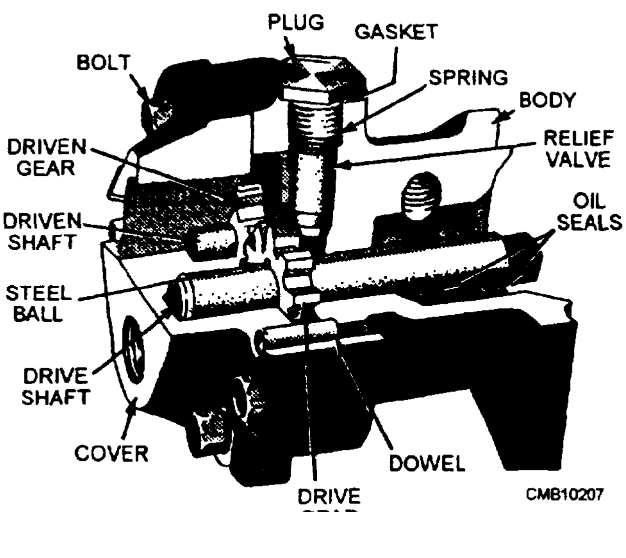


Figure 5-24.—Typical gear fuel pump assembly.

If you are ever in doubt as to the rotation of the fuel pump, it can be identified as follows:

1. Stamped on the pump cover are the letters LH or RH, plus an arrow indicating the direction of rotation.
2. On in-line engines, the rotation of the fuel pump can be determined by its location on the engine. When viewed from the flywheel end: left-hand side location, LH pump rotation; right-hand side location, RH pump rotation.
3. A similar method would be to grasp the pump in your left or right hand, as it mounts on the engine. Whichever thumb covers the relief valves indicates the rotation of the pump.

The letter *I/L* (inlet) is also stamped on the pump cover; however, if not visible, the inlet side is the hole on the pump cover closest to the relief valve plug.

Since the pump constantly circulates a supply of fuel to and through the injectors, the unused fuel cools and lubricates the injectors and purges the system of any air, then returns to the fuel tank via the restricted fitting and return line.

All Detroit diesel engines are equipped with a return Line restricted fitting, the actual size varying with the engine injector size and application. Every restricted fitting has the letter *R* followed by a number that indicates its hole size in thousandths of an inch. Therefore, a fitting with R80 stamped on it indicates a 0.080-inch-diameter hole drilled within the fitting.

These fittings may look like an ordinary brass fittings externally; therefore, care must be taken to ensure that, in fact, the proper restricted fitting, and not just any fitting, is installed into the return line. Use of too large a fitting can lead to a low fuel pressure within the fuel manifold. This condition can cause poor engine performance. A small fitting can lead to increased fuel temperatures and some restriction against the fuel flow. Refer to the service manual of the engine for any particular specifications.

The basic fuel flow is as follows:

- The fuel pump draws fuel from the tank past a one-way no-return check valve into the primary filter. Here the fuel passes through a 30-micron-filtering-capacity, cotton-wound, sock-type element. From the primary filter it passes up to the suction side of the fuel pump. Here the fuel is forced out at 65 to 75 psi to the secondary filter that is a pleated paper element of lo-micron filtering capacity.
- Fuel then passes up to the inlet fuel manifold of the cylinder head where it is distributed through the fuel jumper lines into each injector.
- All surplus fuel (not injected) returns from the injectors through fuel jumper lines to the return fuel manifold, through the restricted fitting, which maintains adequate fuel pressure in the cylinder head at all times, then back to the tank.

Injectors

The fuel injector, or what is often referred to as a **unit injector** (fig. 5-25), is used by Detroit diesel in all series of engine that they build. Certainly, there are some variations in basic design and in the actual testing procedures used; however, the function and operation is the same for all.

Unit injectors were designed with simplicity in mind both from a control and adjustment outlook. They are used on direct-injection, open-type, two-cycle combustion chamber engines manufactured by General Motors. No high-pressure fuel lines or air-fuel mixing or vaporizing devices are required with these injectors. The fuel from the fuel pump is delivered to the inlet fuel manifold (cast internally within the cylinder head) at a pressure of 65 to 75 psi. The fuel then flows to the injectors through fuel pipes called jumper lines. Once the fuel from the pump reaches the injector, it performs the following functions:

1. **Times injection:** liming of the injector is accomplished by movement of the injector control rack, which causes rotation of the plunger within the injector bushing. Since the plunger is manufactured with a helical chamber area, this rotation will either advance or retard closing of the ports in the injector bushing, and therefore the start and end of the actual injection period. Pushrod adjustment establishes the height of the injector follower above the body. In turn, this factor establishes the point or time that the descending plunger closes the bushing ports, allowing injection to begin.

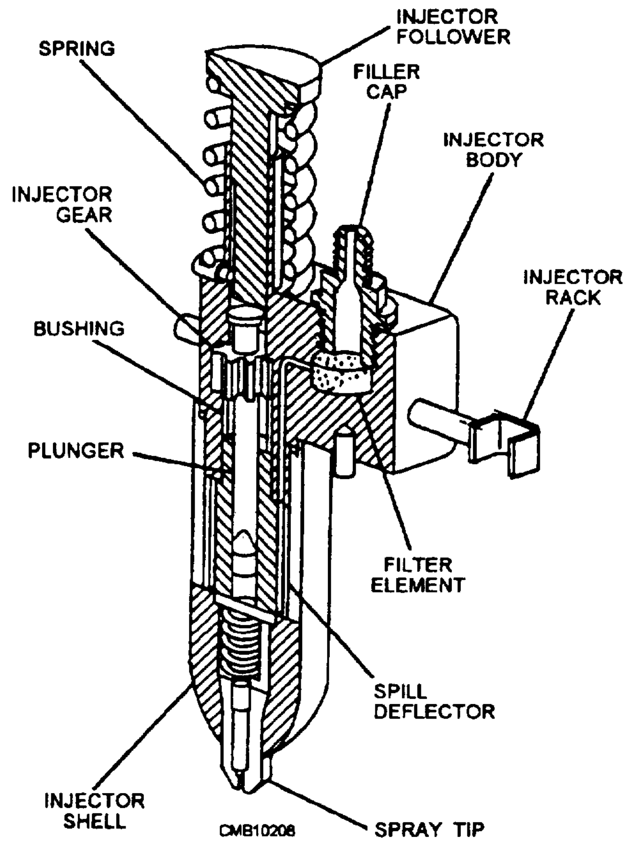


Figure 5-25.—Unit injector.

2. **Meter the fuel:** The rotation of the plunger by movement of the injector control rack will advance or retard the start and end of injection. If the length of time that the fuel can be injected is varied, the amount of fuel will be varied.
3. **Pressurizes the fuel:** Fuel that is trapped underneath the plunger on its downward stroke will develop enough pressure to force its way past the check valve or needle valve, therefore entering the combustion chamber.
4. **Atomizes the fuel:** Fuel under pressure that forces its way past the check or needle valve must than pass through small holes or orifices in the injector spray tip. This passage breaks the fuel down into a finely atomized spray, as it enters the combustion chamber.

The two-stroke Detroit diesel engine unit fuel injector is located in the cylinder head. The injector sits in a copper tube in the head that is surrounded by water for cooling purposes. The injector is placed in the cylinder head by a dowel pin on the underside of its body. The injector is held in place by a single bolt and clamp arrangement. The clamp sits low on the injector body, which allows clearance for the valve bridge operating mechanism. The injector is also known as an offset body because the fuel inlet and outlet are offset to one another. This arrangement allows sufficient clearance between the valves.

Each injector has a circular disc pressed into a recess at the front side of the injector for identification purposes. The identification tag indicates the nominal output of the injector in cubic millimeters. Both the plunger and bushing are marked with corresponding numbers to identify them as mating parts. Therefore, if either the plunger or bushing requires replacement, both must be replaced as an assembly.

The injector control rack for each injector is actuated by a lever on the injector control tube that, in turn, is connected to the governor by mean of a fuel rod. These levers can be adjusted, thus permitting a uniform setting of all injector racks. Basic operation of the unit injector is as follows:

- Fuel, under pressure, enters the injector at the inlet side through a filter cap and filter element. From the filter element, the fuel passes through a drilled passage into the supply chamber—that area between the plunger bushing and the spill deflector and the area underneath the injector plunger within the bushing. The plunger operates up and down in the bushing, the bore of which is open to the fuel supply in the annular chamber by two funnel-shaped ports in the plunger bushing.

- The plunger descends, under pressure of the injector rocker arm, first closing of the lower port and then the upper. Before the upper port is shut off, fuel being displaced by the descending plunger flows up through the "T" drilled hole in the plunger and escapes through the upper port and into the supply chamber.

- With the upper and lower ports closed off, the remaining fuel is subjected to increased pressure by the continued downward movement of the plunger. When sufficient pressure is built up, it opens the flat, non-return, check valve. The fuel is compressed until the pressure force acting on the needle valve is sufficient to open the valve against the downward force of the valve spring. As soon as the needle valve lifts off its seat, the fuel is forced through the small orifices in the spray tip and atomized into the combustion chamber.

- As the plunger continues to descend, it uncovers the lower port, so fuel pressure is relieved, and the valve spring closes the needle valve, ending injection. Then the plunger returns to its original position and waits for the next injection cycle.

Injector Timing

Whenever an injector has been removed and reinstalled or a new injector has been installed in an engine, the injector must be timed and the control rack positioned.

The injector plunger is timed by the fact that it meshes with a flat area on the internal rack gear inside the injector body. It is also timed to the fuel control rack—a dot on the gear that is centered between two dots on the injector control rack. Actual effective length that the plunger moves down in its bushing is controlled by the height of the injector follower above the injector body.

To time an injector properly, adjust the injector follower to a definite height in relation to the injector body (fig. 5-26). This will vary according to the size of the injector being used. This dimension is given in the engine tune-up section of the service manual. Current timing pin dimensions can also be found stamped on the valve rocker cover emissions decal. Be certain that you select the proper timing pin gauge (fig. 5-27); otherwise, the engine will run rough and fail to perform properly under load. In addition, continued operation of the injector set at the wrong timing height can result in engine damage.

All the injectors can be timed in firing-order sequence during one full revolution of the crankshaft on all two-cycle engines. A four-cycle engine requires two revolutions of the crankshaft. The sequence for injector timing is as follows:

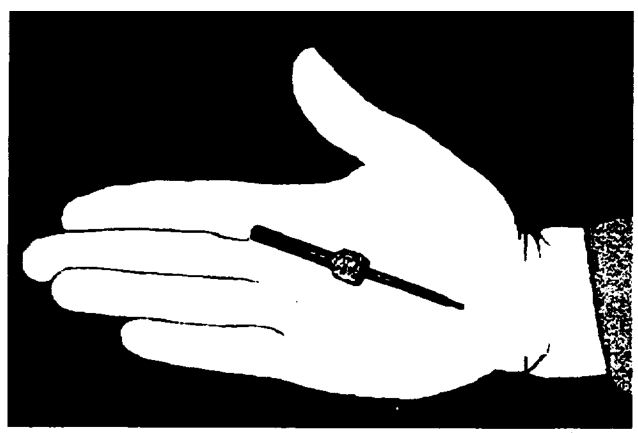

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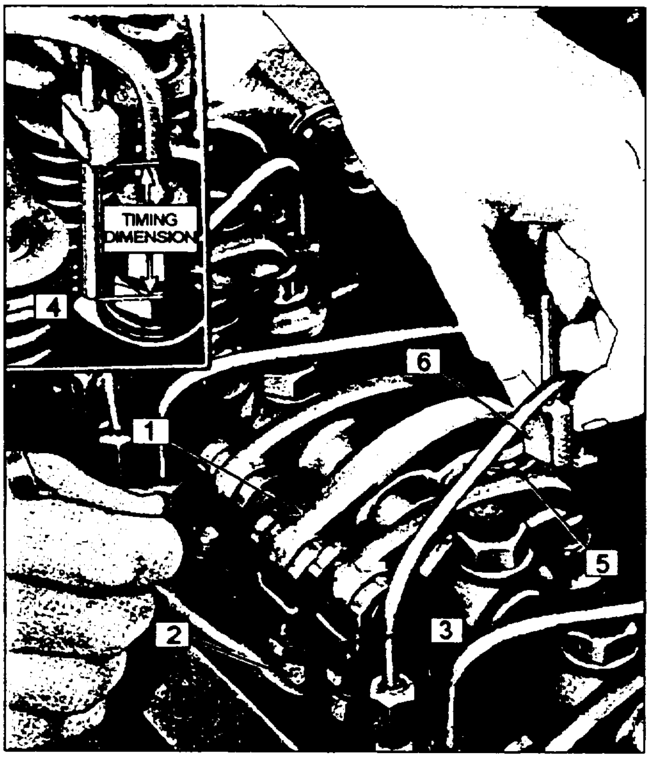
Figure 5-26.—Timing fuel injectors.



1. Rocker injector arm.
2. Push rod.
3. Lock nut.
4. Fuel injector.
5. Injector follower.
6. Injector timing gage.

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Figure 5-27.—Timing gauge.

1. The governor speed control lever should be in the IDLE position. If a stop lever is provided, secure it in the STOP position.
2. Rotate the engine crankshaft, using an engine barring tool, until the exhaust valves are fully depressed on the cylinder that you wish to set the injector. If a barring tool is not available, a 3/4-inch-square drive socket set with a suitable socket to fit over the crankshaft pulley will also do.
3. Insert the small end of the timing pin (gauge) into the hole provided in the top on the injector body, with the flat portion of the gauge facing the injector follower.
4. Gently push the gauge by holding the knurled stem with the thumb and forefinger towards the follower. There should be a slight drag between the gauge and the follower.
5. If this cannot be done, loosen the injector pushrod locknut and adjust it until the drag of the gauge (slight feel) has been determined. Hold the pushrod and tighten the locknut. Recheck the feel, and, if needed, readjust.
6. When hot setting this adjustment, wipe off the top of the injector follower and place a clean drop of oil on it. When properly adjusted, the gauge should just wipe off the oil film from the follower when the slight drag is felt.
7. Time remaining injectors in the same manner.

Equalizing Injectors

Since all the injector racks are connected to the fuel control tube and then to the governor by the fuel rod or rods, they must be set correctly. This ensures that they are equally related to the governor. Their positions determine the amount of fuel that will be injected into the individual cylinders, ensuring equal distribution of the load. Failure to set the racks properly will result in poor performance and a lack-of-power complaint.

Adjusting the inner and outer adjusting screws on the rack control lever (fig. 5-27) equalizes the injectors. This is a rather delicate adjustment. and it may be necessary to make these adjustments several times before the engine operates just right.

To increase the amount of fuel injected, loosen the outer adjusting screw and tighten the inner adjusting screw, thereby moving the control rack inward. To decrease fuel injection, loosen the inner adjusting screw slightly and tighten the outer adjusting screw which moves the control rack outward. In making the operating adjustments, never turn the adjusting screws more than one-fourth turn at a time; for if one injector is adjusted too far out of line with the others, it will prevent the full travel of the racks and reduce the maximum power to the engine.

NOTE

For exact procedures for adjusting the injector rack control levers, refer to the manufacturer's service manual.

Sometimes smoother engine operation can be obtained by making slight changes to the adjustments after the engine is warmed to operating temperature (above 140°F). For example, one cylinder may not be carrying its share of the load as indicated by a comparatively cooler cylinder. Therefore, the control rack should be adjusted for more fuel. A slight knocking noise from another cylinder would indicate an adjustment for slightly less fuel.

Do not attempt to obtain a smooth running engine by changing control-rack settings without first timing and equalizing injection in the recommended manner.

Governor

Detroit diesel engines use both mechanical and hydraulic governors on the engines of the following type:

1. Mechanical limiting speed governor
2. Variable mechanical speed governor
3. Variable low-speed limiting speed mechanical governor
4. Mechanical constant speed governor (earlier engines)
5. Dual-range limiting speed mechanical governor
6. Woodward SG hydraulic governor
7. Woodward PSG hydraulic governor
8. Woodward electric governor

On Detroit diesel engines the type of governor used is dependent on the particular engine application; therefore, setup can vary slightly between engines. All Detroit diesel mechanical governors are easily identifiable by a nameplate attached to the governor housing. The following letters are typical examples.

DWLS: double-weight limiting speed (mobile equipment)

SWLS: single-weight limiting speed (mobile equipment)

SWVS: single-weight variable speed (industrial and marine)

VLSLS: variable low-speed limiting speed (highway vehicles)

DWDRG: double-weight dual range governor (highway vehicles)

SG, PSG, SGX, UG8: Woodward hydraulic-type governors (industrial and generator sets)

The functions of all these governors, whether mechanical or hydraulic, are to control engine speed and correct for any change in load applied or removed from the engine. They all work on the basic principle of weights against spring pressure; therefore, all governors are of the speed-sensing type.

Since the action of all these governors is the same, but with a difference only in purpose, we will discuss the two most common types found on a Detroit diesel engine—the limiting and variable speed governors.

The limiting speed type governor is found in both single- and double-weight version and can also be found on both in-line and V-type engines. Riveted on the side of the governor housing is an identification plate, which shows the following:

1. Governor part number
2. Date of manufacture
3. Idle speed range
4. Type, such as DWLS, meaning double-weight limiting speed
5. Drive ratio

Regardless of whether the limiting speed governor is of the single- or double-weight variety, the action of the governor is the same. The purpose of the limiting speed governor is as follows:

1. Controls engine idle speed
2. Limits the maximum speed of the engine

The application of the engine determines whether a single- or double-weight governor will be used. The most prominent application for the limiting speed governor is highway truck engines, since the governor has no control in the intermediate engine speed range. This allows the operator to have complete control of the injector rack movement through throttle action alone. This permits fast throttle response for engine acceleration or deceleration.

The variable speed mechanical governor is found extensively on industrial and marine applications, since it is designed for the following functions:

1. Controls the engine idle speed
2. Controls the maximum engine speed
3. Holds the engine speed at any position between idle and maximum as desired and set by the operator.

The response and reaction of the variable speed mechanical governor is similar to that of the limiting speed type with just a few exceptions. Since the variable speed mechanical governor controls speed throughout the total rpm range, there is no intermediate range as with the limiting speed governor. The variable speed governor uses only one set of weights and one spring.

In a variable speed mechanical governor, any given throttle setting or load from idle to maximum speed, a state of balance can exist. If, however, the load is increased or decreased, a corrective action will be initiated. The bell crank lever and pivoting differential lever will be moved by the action of the governor spring or weights to reestablish a state of balance.

Remember the governor can only react and change to the rpm of the engine.

The variable speed mechanical governor is readily identifiable from the limiting speed governor by the fact that it has only one lever on the top of the governor cover, which is the stop/run lever. The speed control lever is located vertically on the end of the governor spring housing. A large booster spring is attached between the speed control lever and a bracket on the cylinder head, used to assist the operator in overcoming governor resistance during throttle movement. The letters *SWVS* (single-weight variable speed) are stamped on the governor identification plate.

NOTE

Before performing any adjustments or repairs to the governor, it is recommended that you consult the manufacturer's service manual.

CUMMINS DIESEL FUEL SYSTEMS

Over the years Cummins has produced a series of innovations, such as the first automotive diesel, in addition to being the first to use supercharging and then turbocharging. All cylinders are commonly served through a low-pressure fuel line. The camshaft control of the mechanical injector controls the timing of injection throughout the operating range. This design eliminates the timing-lag problems of high-pressure systems.

To meet Environmental Protection Agency (EPA) exhaust emissions standards, Cummins offers the Celect (electronically controlled injection) system. Since the Celect system did not start production until 1989, there are literally thousands of Cummins with pressure-time (PT) fuel systems. We will discuss the operation of the PT system first, then discuss the basic operating concept of the Celect system.

Pressure-Time Fuel System

The pressure-time (PT) fuel system (fig. 5-28) is exclusive to Cummins diesel engines; it uses injectors that meter and injects the fuel with this metering based

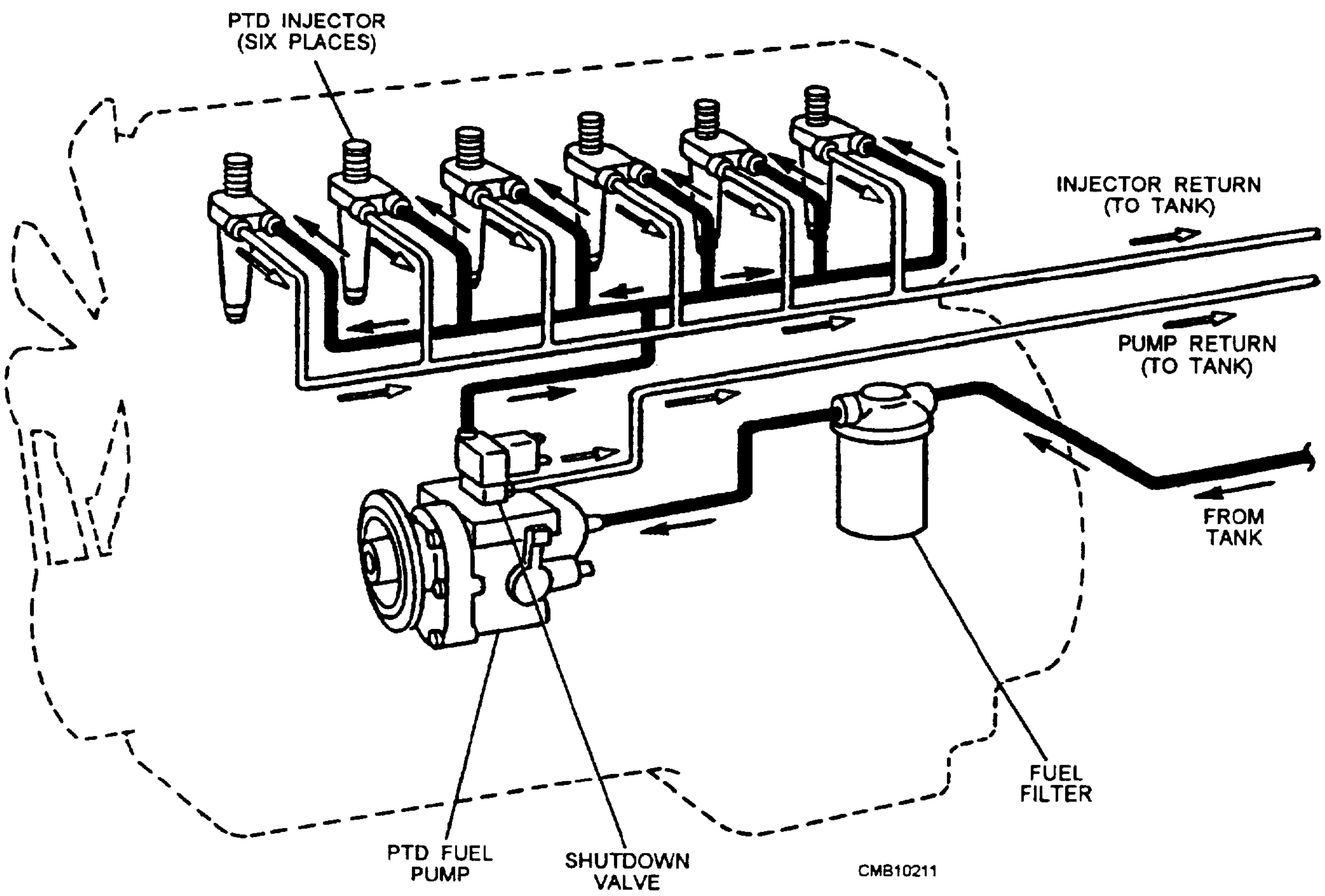


Figure 5-28.—Pressure-time fuel system.

on a pressure-time principle. A gear-driven positive displacement low-pressure fuel pump naturally supplies fuel pressure. The time for metering is determined by the interval that the metering orifice in the injector remains open. This interval is established and controlled by the engine speed, which determines the rate of camshaft rotation and consequently the injector plunger movement.

Since Cummins engines are all four-cycle, the camshaft is driven from the crankshaft gear at one-half of engine speed. The fuel pump turns at engine speed. Because of this relationship, additional governing of fuel flow is necessary in the fuel pump.

A flyball type mechanical governor controls fuel pressure and engine torque throughout the entire operating range. It also controls the idling speed of the engine and prevents engine overspeeding in the high-speed range. The throttle shaft is simply a shaft with a hole; therefore, the alignment of this hole with the fuel passages determines pressure at the injectors.

A single low-pressure fuel line from the fuel pump serves all injectors; therefore, the pressure and the amount of metered fuel to each cylinder are equal.

The fuel-metering process in the IT fuel system has three main advantages:

1. The injector accomplishes all metering and injection functions.
2. The injector injects a finely atomized fuel spray into the combustion chamber at spray-in-pressures exceeding 20,000 psi.
3. A low-pressure common-rail system is used, with the pressure being developed in a gear-type pump. This eliminates the need for high-pressure fuel lines running from the fuel pump to each injector.

FUEL PUMP.—The fuel pump (fig. 5-29) commonly used in the pressure-time system is the PTG-AFC pump (PT pump with a governor and an air-fuel control attachment). The "P" in the name refers to the actual fuel pressure that is produced by the gear pump

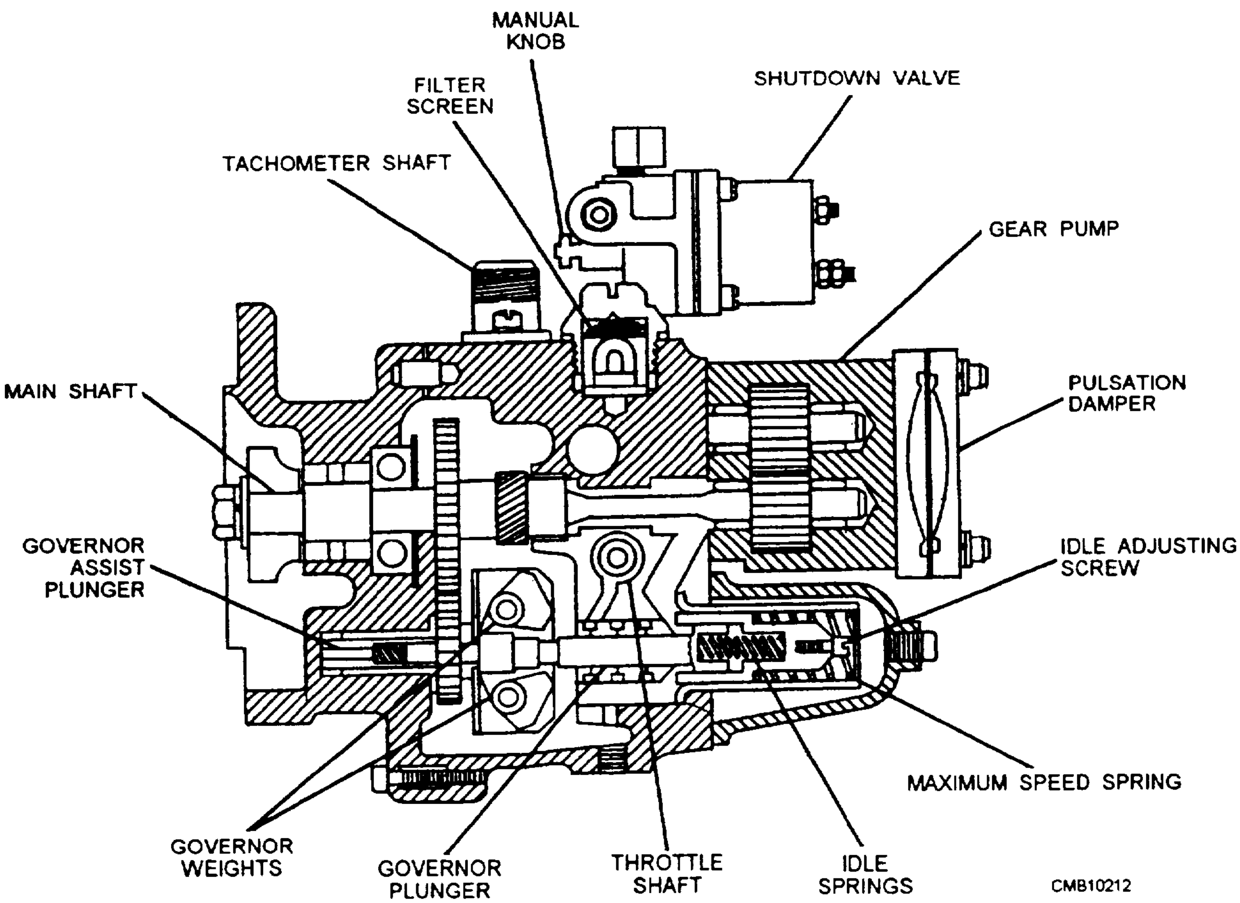


Figure 5-29.—Pressure-time (PT) gear pump.

and maintained at the inlet to the injectors. The "T" refers to the fact that the actual "time" available for the fuel to flow into the injector assembly (cup) is determined by the engine speed as a function of the engine camshaft and injection train components.

The air-fuel control (AFC) is an acceleration exhaust smoke control device built internally into the pump body. The AFC unit is designed to restrict fuel flow in direct proportion to the air intake manifold pressure of the engine during acceleration, under load, and during lug-down conditions.

Within the pump assembly a fuel pump bypass button of varying sizes can be installed to control the maximum fuel delivery pressure of the gear-type pump before it opens and bypasses fuel back to the inlet side of the pump. In this way the horsepower setting of the engine can be altered fairly easily. The major functions of the PTG-AFC fuel pump assembly are as follows:

1. To pull and transfer fuel from the tank and filter
2. To develop sufficient fuel pressure to the fuel rail (common fuel passage) to all of the injectors
3. To provide engine idle speed control (governing)
4. To limit the maximum no-load and full-load speed of the engine (governing)
5. To allow the operator to control the throttle position and therefore the power output of the engine
6. To control exhaust smoke emissions to EPA specifications under all operating conditions
7. To allow shutdown of the engine when desired

A major feature of the PT pump system is that there is no need to time the pump to the engine. The pump is designed simply to generate and supply a given flow rate at a specified pressure setting to the rail to all injectors. The injectors themselves are timed to ensure that the start of injection will occur at the right time for each cylinder.

The basic flow of fuel into and through the PT pump assembly will vary slightly depending on the actual model. A simplified fuel flow is as follows:

- As the operator cranks the engine, fuel is drawn from the fuel tank by the gear pump through the fuel supply line to the primary filter. This filter is normally a filter/water separator.
- The filter fuel then flows through a small filter screen that is located within the PT pump assembly, and then flows down into the internal governor sleeve.
- The position of the governor plunger determines the fuel flow through various governor plunger ports.
- The position of the mechanically operated throttle determines the amount of fuel that can flow through the throttle shaft.
- Fuel from the throttle shaft is then directed to the AFC needle valve.
- The position of the AFC control plunger within the AFC barrel determines how much throttle fuel can flow into and through the AFC unit and on to the engine fuel rail, which feeds the fuel rail.

The AFC plunger position is determined by the amount of turbocharger boost pressure in the intake manifold, which is piped through the air passage from the intake manifold to the AFC unit. At engine start-up, the boost pressure is very low; therefore, flow is limited. Fuel under pressure flows through the electric solenoid valve, which is energized by power from the ignition switch. This fuel then flows through the fuel rail pressure line and into the injectors.

A percentage of the fuel from both the PT pump and the injectors is routed back to the fuel tank in order to carry away some of the heat that was picked up cooling and lubricating the internal components of the pump and the injectors.

INJECTORS.—A PT injector is provided at each engine cylinder to spray the fuel into the combustion chambers. PT injectors are of the unit type and are operated mechanically by a plunger return spring and a rocker arm mechanism operating off the camshaft. There are four phases of injector operation, which are as follows:

- **Metering** (fig. 5-30)—The plunger is just beginning to move downward and the engine is on the beginning of the compression stroke. The fuel is trapped in the cup, the check ball stops the fuel flowing backwards, and fuel begins to be pressurized. The excess fuel flows around the lower annular ring, up the barrel, and is trapped there.

- **Pre-injection** (fig. 5-30)—The plunger is almost all the way down, the engine is almost at the end of the compression stroke, and the fuel is being pressurized by the plunger.

- **Injection** (fig. 5-30)—The plunger is almost all the way down, the fuel injected out the eight orifices, and the engine is on the end of the compression stroke.

- **Purging** (fig. 5-30)—The plunger is all the way down, injection is complete, and the fuel is flowing into the injector, around the lower annular groove, up a drilled passageway in the barrel, around the upper annular groove, and out through the fuel drain. The cylinder is on the power stroke. During the exhaust stroke, the plunger moves up and waits to begin the cycle all over.

Injector adjustments are extremely important on PT injectors because they perform the dual functions of metering and injecting. Check the manufacturer's manual for proper settings of injectors. On an engine where new or rebuilt injectors have been installed, initial adjustments can be made with the engine cold. Always readjust the injectors, using a torque wrench calibrated in inch-pounds after the engine has been warmed up. Engine oil temperature should read between 140°F and 160°F.

Anytime an injector is serviced, you must be certain that the correct orifices, plungers, and cups are used, as these can affect injection operation. You can also affect injection operation by any of the following actions:

- Improper timing.

- Mixing plungers and barrels during teardown (keep them together, since they are matched sets).

- Incorrect injector adjustments after installation or during tune-up adjustment.

- Installing an exchange set of injectors without taking time to check and correct other possible problems relating to injection operation. This is often overlooked.

Proper injector adjustment and maintenance will ensure a smooth running engine as long as the following factors are met:

1. Adequate fuel delivery pressure from the fuel pump to the fuel manifold.
2. Selection of the proper sizes of balance and metering orifices.
3. The length of time that the metering orifice is uncovered by the upward moving injector plunger.

NOTE

For required adjustments and maintenance schedules, always consult the manufacturer's service manual.

Celect System

The Celect system is a full electronic controlled injection and governing system. The major reason behind the adoption of electronic fuel injection control is to be able to meet not only the EPA (Environmental Protection Agency) exhaust emission controls but also ensure optimum fuel economy. This is done by constantly monitoring major engine operating parameters that have a direct bearing on engine combustion efficiency. A number of engine- and vehicle-mounted sensors are used to update timing and metering values continually. The Celect system controls the following major operating factors:

1. Engine torque and horsepower curves
2. AFC (air-fuel control) to limit exhaust smoke
3. Engine low idle and high speeds
4. Functions as a vehicle road speed governor
5. Optional vehicle/engine cruise control
6. PTO (power takeoff) operation
7. Idle shutdown, 3 to 60 seconds
8. Gear down protection

For the Celect system to operate, major components are required. These components are as follows:

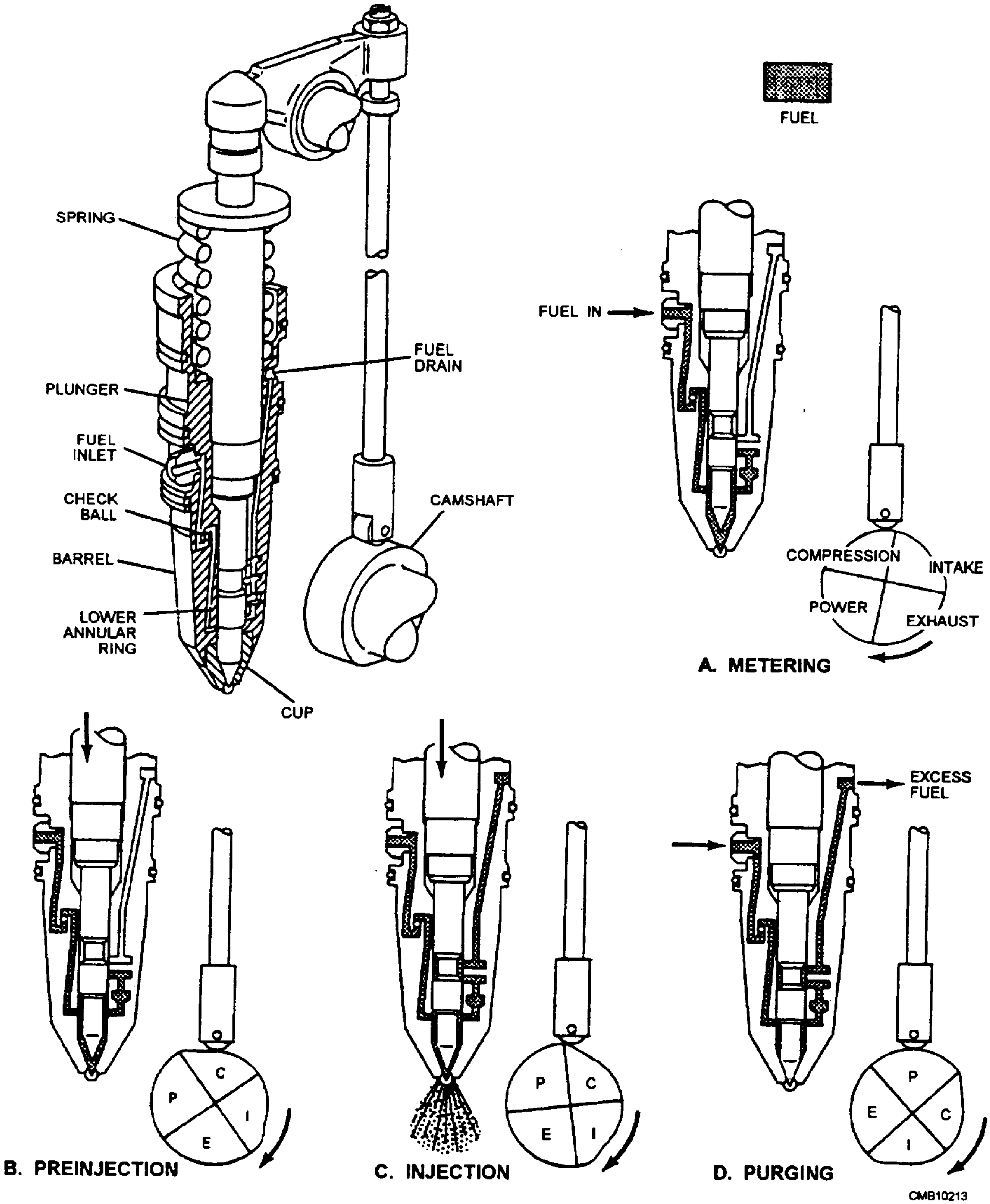


Figure 5-30.—Pressure-time injector operation.

1. The electronic control module (ECM) contains the hardware required to activate the ECI system. Within the ECM are such controls as the EPROM (electrically erasable programmable read-only memory), CPU (central processing unit), RAM (random access memory), and also contain in the ECM is the A/D (analog/digital) converter. The ECM sends electrical signals to the injectors, engine brake solenoids, the fuel shutoff valve, and other optional items. The ECM is mounted to a cooling plate which has diesel fuel continually routed through it from the pump in order to keep the internal solid-state components at a safe operating temperature.
2. The engine position sensor (EPS) is required to tell the ECM where the various pistons are and what stroke they are on, so the correct injector solenoid can be activated at the right time.
3. The oil temperature sensor (OTS) is used to advise the ECM of the oil temperature. The signal is used by the ECM to determine the engine idle speed at start-up as well as reducing the fueling rate any time the oil temperature rises to an undesirable level.
4. The oil pressure sensor (OPS) is used by the ECM to monitor engine oil pressure during operation.
5. The coolant temperature sensor (CTS) is used to monitor the temperature of the engine coolant.
6. The coolant level sensor (CLS) is used to tell the ECM of a coolant level loss.
7. The ambient air pressure sensor (APS) is used by the ECM to determine the basic operating altitude of the vehicle.
8. The intake manifold temperature sensor (IMTS) allows the ECM to determine air temperature and adjust fuel rate accordingly.
9. The throttle position sensor (TPS) is basically a potentiometer or variable resistor arrangement that is designed to a output voltage signal to the ECM, based on the degree of the throttle pedal depression. The ECM is able to determine how much fuel the operator is asking for.
10. The vehicle speed sensor (VSS) is required to tell the ECM the road speed of the vehicle. The VSS sensor is mounted into the transmission output shaft housing in order to monitor the output shaft speed.
11. The electronically controlled injectors receive low-pressure fuel from a simple engine-driven gear pump. Each injector is mechanically operated; however, timing and duration of injection is controlled electronically by a signal from the ECM. This signal is referred to as pulse-width-modulated (PWM). The longer the PWM signal is, the longer the injector will deliver fuel to the combustion chamber. The greater the fuel delivery, the greater the horsepower produced.

Two other major control switches are required with the Celect-ECI system in order to control the cruise control, the PTO (power takeoff), and the engine compression brake:

1. A clutch switch is used to allow cruise control or engine brake activation. It is mounted so that when the clutch pedal is pushed down (clutch disengaged), the clutch switch opens the switch and deactivates the engine brake or PTO.
2. A brake switch is located in the service air line and will remain in the closed position any time the brakes are released. Applying the brakes will cause the brake switch to open and break the electrical circuit to both the cruise control and PTO systems.

In addition to the engine-mounted components, there are several cab-mounted controls arranged on a small control panel that can be activated by the operator through a series of small toggle-type switches. This control panel contains the following:

- The idle-speed adjustment switch is used to adjust the engine idle speed between 550 and 800 rpm. Each time the switch is moved briefly to the + or – position, the idle speed will change by approximately 25 rpm.
- The cruise control panel has two toggle switches—one is a simple ON/OFF switch and the other is the actual cruise control position select switch that the operator uses to set and adjust the cruise control speed during operation.
- The engine brake panel has two toggle switches—one switch has an ON/OFF position to activate either a Jacobs or Cummins "C" brake system and the other switch, used with the engine

brake control, can be placed into position 1, 2, or 3. In position 1 the compression brake is activated only on two cylinders; position 2 will activate the compression brake on four cylinders; position 3 will allow all six cylinders to provide compression braking.

On the right-hand side of the control panel are two warning lights—one yellow, the other one red. The yellow light is labeled warning, while the red light is labeled stop. When the yellow light comes on during engine operation, this indicates that a Celect system problem has been detected and recorded in the ECM memory. The problem is not serious enough to shut down the engine, but should be checked out at the earliest opportunity. If the red light comes on, the operator should immediately bring the vehicle to a stop and shut off the engine.

Celect System Operation

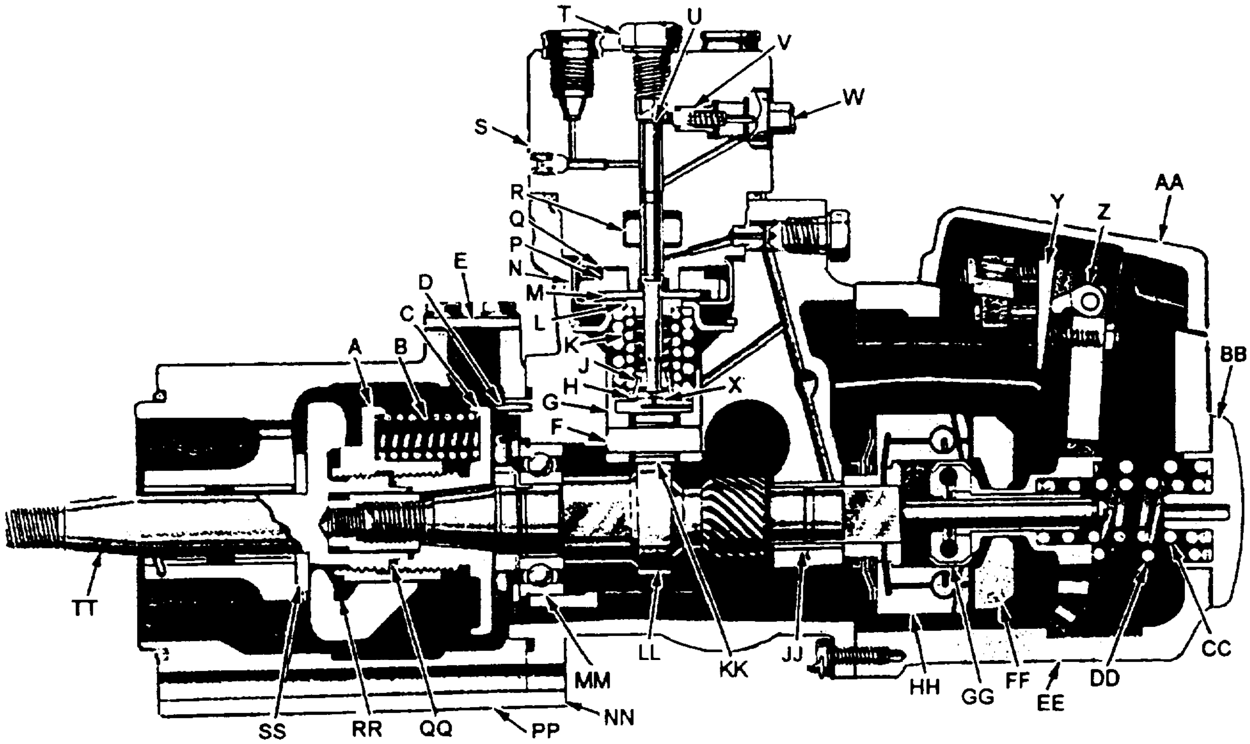
The ECI (electronically controlled injection) Celect system uses an engine-driven gear pump to pull fuel from the fuel tank. The fuel is passed through a primary filter or filter/water separator unit, then to the ECM where the fuel is circulated through a cooling plate. The cooling plate, mounted to the rear of-the ECM, ensures adequate cooling of the electronic package.

The gear pump is designed to deliver fuel to the fuel manifold at 140 psi, which supplies the electronically controlled injectors. A spring-loaded bypass valve allows excess fuel under pressure to return to the suction side of the pump to maintain maximum system pressure.

A rocker arm and pushrod assembly mechanically operates the injector. The injector requires rocker arm actuation of the plunger to create high fuel pressure for injection. To control both the start of injection timing and the quantity of fuel metered, the ECM sends out a pulse-width-modulated (PWM) electrical signal to each injector. The PWM signal determines the start of injection, while the duration of this signal determines how long the injector can effectively continue to spray fuel into the combustion chamber, as the plunger is forced down by the rocker arm assembly. A shorter PWM signal means that the effective stroke of the injector plunger will be decreased. A longer PWM signal means that the effective stroke will be increased. The start of injection and the duration of the PWM signal is determined by the ECM, based on the various input sensor signals and the preprogrammed PROM information within the ECM. Each PROM is designed for a specific engine/vehicle combination, based on the desired horsepower setting and rpm, the tire size, and gear ratios used in the vehicle.

Contained within the injector are a timing plunger, a return spring, and an injector control valve—that is the key to the operation. The control valve is electrically operated, receiving signals from the ECM to energize/de-energize, which determines the start of injection. The length of time that this solenoid is energized determines the quantity of metered fuel to be injected into the combustion chamber. Also within the injector body is a metering spill port which must be closed to allow injection, a metering piston, the bias spring, and the spill-timing port. The injection sequence of events occur as follows:

1. The injector receives a signal from the ECM; the injector control valve will close and the metering phase begins while the metering piston and timing plunger are bottomed in the injector.
2. As the camshaft rotates, the injector pushrod cam follower will ride down the cam ramp, thereby allowing the rocker arm and pushrod to be forced up by the energy of the timing plunger return spring. Fuel at gear pump pressure of 140 psi can flow into the fuel supply passage and unseat the lower check valve, allowing the metering chamber to be charged with pressurized fuel as long as the timing plunger is being pulled upward by the force of the large external spring. Fuel pressure, acting on the bottom of the metering piston, forces it to maintain contact with the timing plunger within the bore of the injector body.
3. Metering ends when the ECM energizes the injector control valve, causing it to open. Pressurized fuel can flow through the open injector control valve into the upper timing chamber, which stops the upward travel of the metering piston. To ensure that the metering piston remains stationary, the small bias spring in the timing chambers holds it in place, while the timing plunger continues upward due to camshaft rotation. Fuel and spring pressure, acting on the metering piston, will ensure fuel pressure is maintained below the piston to keep the lower metering ball-check valve closed. This allows a precisely metered quantity of fuel to be trapped in the metering chamber.
4. As long as the timing plunger moves upward due to the rotating camshaft lobe action and the



CMB10214

A - Sliding gear
B - Advance unit spring
C - Advance unit hub
D - Timing pointer
E - Timing cover
F - Tappet roller pin
G - Tappet guide
H-Spring lower seat
J - Plunger lock
K-Plunger inner spring
L - Spring upper seat
M - Plunger guide
N - Drive gear retainer
P-Plunger drive gear
Q-Gear thrust washer
R - Plunger sleeve
S - Hydraulic head
T -Plunger bore screw
U - Fuel plunger
V -Fuel delivery valve
W - Delivery valve screw
X - Plunger button
Y - Stop plate
Z - Smoke limit cam
AA - Governor cover
BB - Governor end cap
CC - Governor inner spring
DD - Governor outer spring
EE - Governor housing
FF - Governor weight
GG - Sliding sleeve
HH - Friction drive spider
JJ - Camshaft bushing type bearing
KK - Tappet roller
LL - Camshaft
MM - Camshaft ball bearing
NN - Injection pump housing
PP - Advance unit housing
QQ - End play spacer
RR - Sliding gear spacer
SS - Spider thrust plate
TT - Spider assembly

Figure 5-31.—Metering and distributing fuel pump assembly-left sectional view.

force of the external return spring on the ECI injector, the upper timing chamber will continue to fill with pressurized fuel.

5. When the engine camshaft lobe starts to lift the injector cam follower roller, the pushrod moves up and the rocker arm reverses this motion to push the timing plunger downward. On the initial downward movement, the injector control valve remains open and fuel flows from the timing chamber and through the control valve to the fuel supply passage. When the ECM closes the control valve, fuel is trapped in the timing chamber; this fuel acts as a solid hydraulic link between the timing plunger and metering piston. The downward movement of the timing plunger causes a rapid pressure increase in the trapped fuel within the metering chamber. At approximately 5,000 psi, the tapered needle valve in the tip of the injector will be lifted against the force of its return spring and injection begins.

6. Injection will continue until the spill passage of the downward-moving metering piston uncovers the spill port. Fuel pressure within the chamber is lost and the needle valve reseats by spring pressure. This terminates injection. Immediately after the metering spill port is uncovered, the upper edge of the metering piston also passes the timing spill port to allow fuel within the upper timing chamber to be spilled back to the fuel drain, as the timing plunger completes its downward movement. Injection has now been completed.

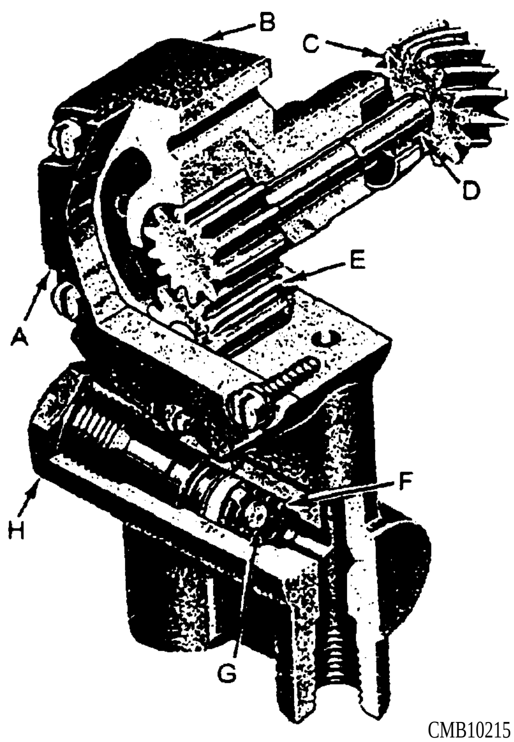
AMERICAN BOSCH FUEL INJECTION SYSTEMS

The American Bosch fuel injection system is used on multifuel engines. The pump meters and distributes fuel. It is a constant-stroke, distributing-plunger, and sleeve-control type of pump. As with other fuel systems, only clean fuel should be used. Good maintenance of the filtering system and reasonable care in fuel handling will give trouble-free operation. Fuels used in the multifuel engine must contain sufficient lubrication to lubricate the fuel pump and injectors. Because of close tolerances, extreme cleanliness and strict adherence to service instructions are required when it is time to service this system.

Fuel Pump

The PSB model fuel pump is similar to other distributor fuel system, in that a pump sends a measured amount of fuel to each injector at a properly timed interval. The difference in the PSB system is that the amount of fuel sent directly from the pump at high enough pressure needed for injection. This eliminates the need for unit-type injectors and the associated linkage and camshaft, making the system less cumbersome.

The purpose of the fuel pump (fig. 5-31) is to deliver measured quantities of fuel accurately under high pressure to the spray nozzle for injection. The positive displacement fuel supply pump (fig. 5-32) is gear-driven by the pump camshaft through an engine camshaft gear and provides fuel to the hydraulic head for injection and cooling.



A - Housing cover

B - Supply pump housing

C - Camshaft driven gear

D-Drive shaft

E - Idler gear

F -Check valve spring

G - Check valve

H - Valve screw

Figure 5-32.—Fuel supply pump assembly—sectional view.

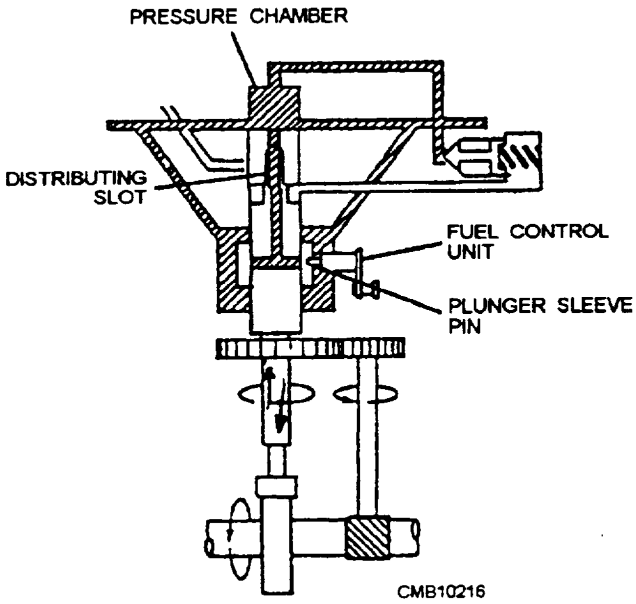


Figure 5-33.—Fuel intake flow diagram.

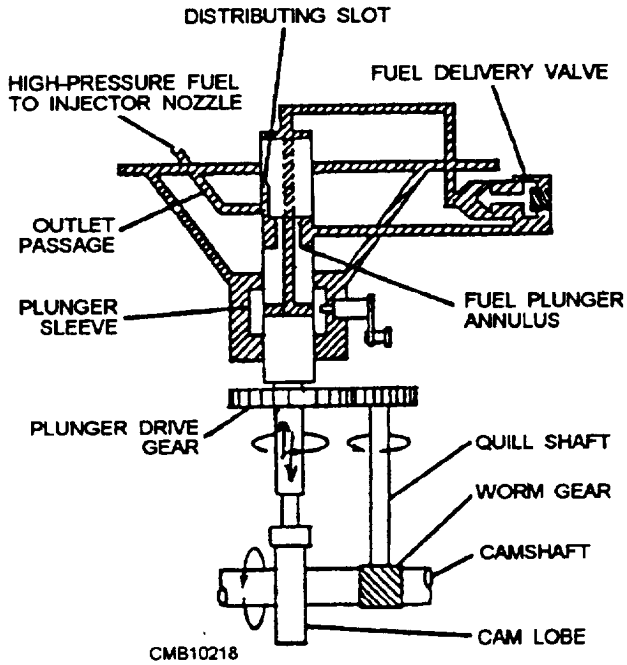


Figure 5-35.—Fuel delivery flow diagram.

Figure 5-33 shows fuel intake at the hydraulic head. Injection (fig. 5-34) begins when fuel flows around the fuel plunger annulus (fig. 5-35) through the open distributing slot to the injection nozzle. A continued upward movement of the fuel plunger causes the spill passage to pass through the plunger sleeve (fig. 5-36). This reduces pressure, allowing the fuel delivery valve to close, ending injection. This is accomplished through a single plunger, multi-outlet hydraulic head assembly (fig. 5-31).

The plunger is designed to operate at crankshaft speed on four-cycle engines. It is actuated by a camshaft and tappet arrangement. The pump camshaft, which also includes the gearing for fuel distribution, is supported on the governor end by a bushing-type bearing and by a ball roller bearing on the driven end. An integral mechanical centrifugal governor (fig. 5-37), that is driven directly from the pump camshaft without gearing, controls fuel delivery in relation to engine speed. This pump has a smoke limit cam within the governor housing to assist in controlling exhaust smoke of various fuels. The mechanical centrifugal advance unit of this pump provides up to g-degrees advance timing and is driven clockwise at crankshaft speed.

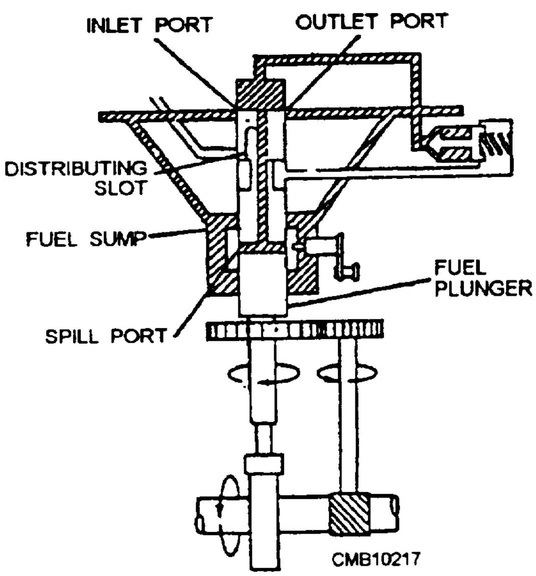


Figure 5-34.—Beginning of fuel delivery flow diagram.

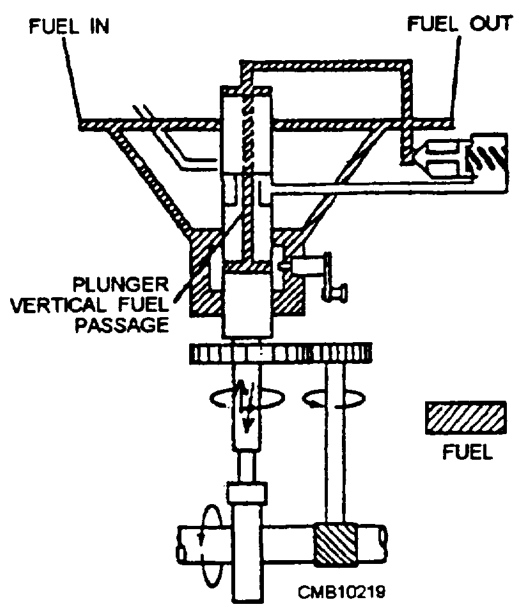
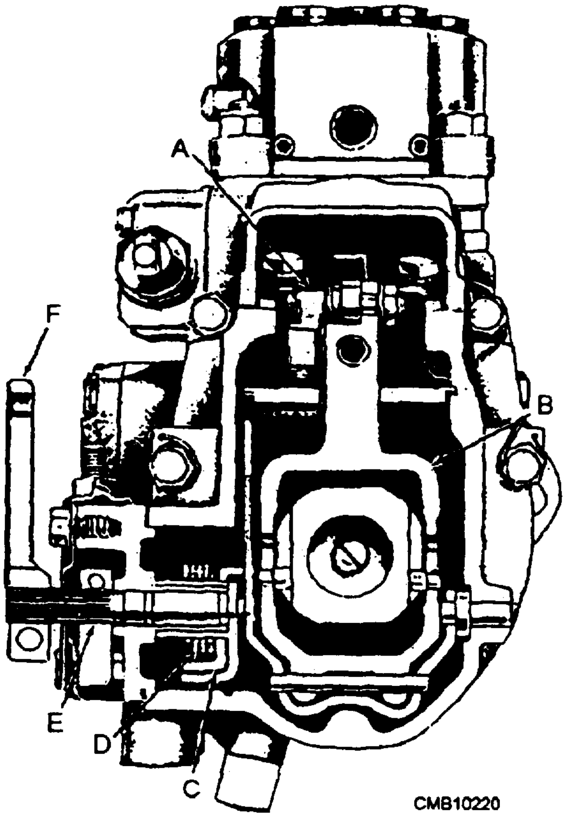


Figure 5-36.—End of fuel delivery flow diagram.



A - Fuel control rod
B - Fulcrum lever
C - Shaft spring plate
D - Operating shaft spring
E - Operating shaft
F - Operating lever

Figure 5-37.—Governor—sectional view.

Types of Nozzles

Bosch nozzles are inward opening with a multiple orifice and hydraulically operated nozzle valve. The two models of this nozzle in use are the American Bosch and Robert Bosch. They may be easily identified by either the length of the nozzle tip holding nut or the nozzle drilling code on the smaller diameter of the nozzle valve body. The American Bosch nozzle nut is 3 inches long, and the nozzle tip has a hand-printed drilling code. The Robert Bosch nozzle nut is 2 inches long, and the nozzle tip has a machined-etched drilling code. Component parts, although similar, are not interchangeable between the two nozzles.

Nozzle Operation

The pressurized fuel from the injection pump enters the top of the nozzle body and flows through a passage in the body and nozzle spring retainer. An annular groove in the top face of the nozzle valve body fills with fuel, and two passages in the nozzle valve body direct fuel around the nozzle valve. When the fuel in the pressure chamber reaches a predetermined pressure, the spring force (adjusted by shims) is overcome and injection occurs. Atomized fuel sprays from the orifice holes in the nozzle tip, as the nozzle valve is opened inward by pressurized fuel. When injection ends, spring pressure snaps the valve in its seat. During each injection, a small quantity of high-pressurized fuel passes between the nozzle valve stem and the nozzle valve body to lubricate and to cool the nozzle valve. A manifold that connects to all of the nozzles returns this fuel to the tank.

Fuel Density Compensator

The multifuel engine operates on a variety of fuels that have a broad range of viscosities and heat values. These variations in the fuels affect engine output. Because it is unacceptable for the power output of the engine to vary with fuel changes, the multifuel engine is fitted with a device known as a fuel density compensator (fig. 5-38). ‘The fuel density compensator is a device that serves to vary the quantity of fuel injected to the engine by regulating the full-load stop of the fuel pump. The characteristics of the fuels show that their heat values decrease almost inversely proportional to their viscosities. The fuel density compensator uses viscosity as the indicator for regulating fuel flow. Its operation is as follows:

- The fuel enters the compensator through the fuel pressure regulator where the fuel pressure is regulated to a constant 20 psi regardless of engine speed and load range.
- The pressure-regulated fuel then passes through a series of two orifices. The two orifices, by offering greatly different resistances to flow, form a system that is sensitive to viscosity changes. The first orifice is annular, formed by the clearance between the servo piston and its cylinder. This orifice is sensitive to viscosity. The second orifice is formed by an adjustable needle valve and is not viscosity sensitive.

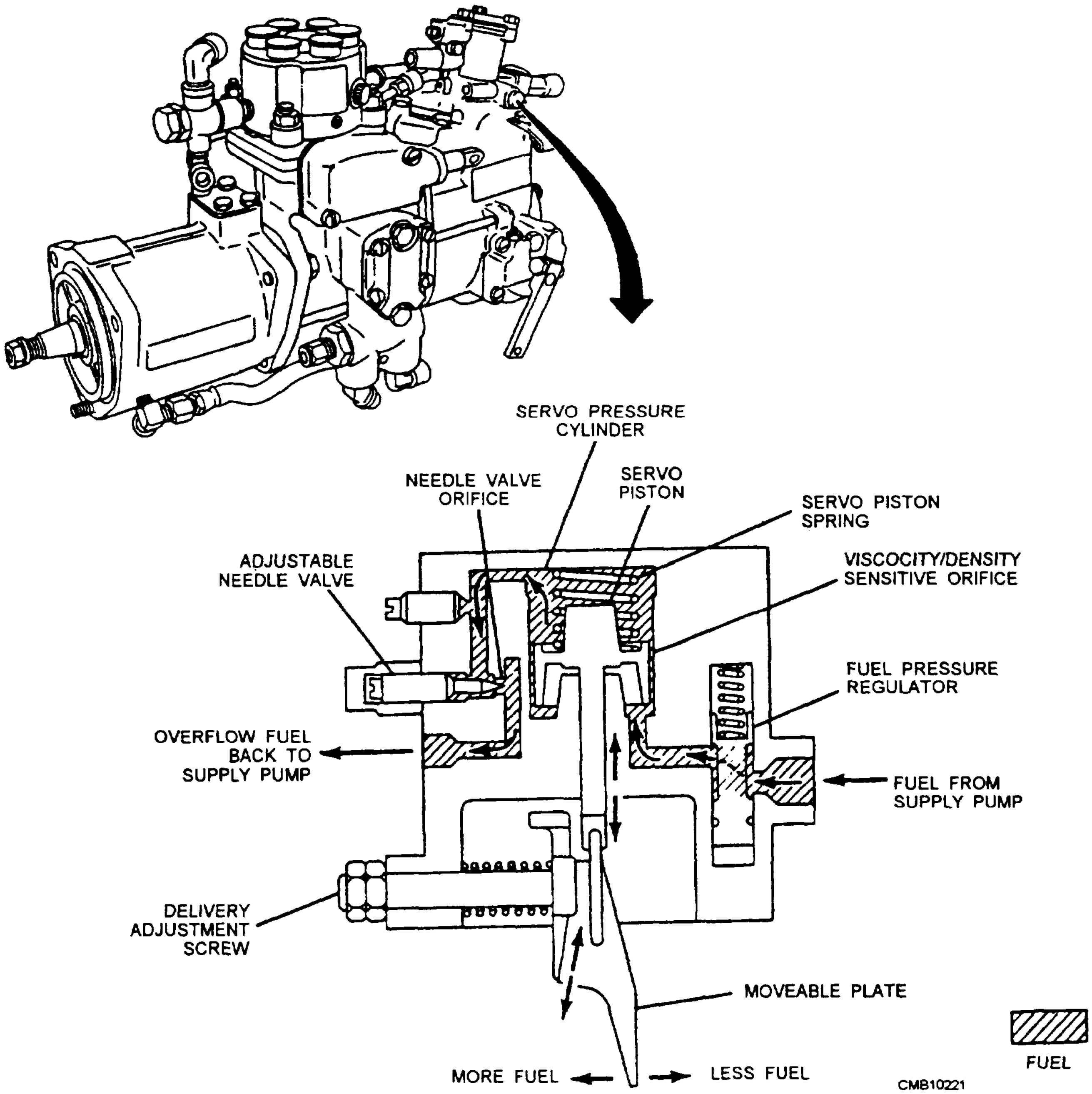


Figure 5-38.—Fuel density compensator.

- The higher the viscosity of the fuel, the more trouble that it will have passing through the first orifice. Because of this, the fuel pressure under the servo piston will rise proportionally with viscosity. Because the second orifice is not viscosity sensitive, the pressure over the servo piston will remain constant. This will cause a pressure differential that increases proportional with viscosity, in turn, causing the piston to seek a position in its bore that becomes higher as viscosity increases.

- The upward movement of the servo piston will move a wedge-shaped moveable plate, which will decrease fuel delivery. A lower viscosity fuel will cause the piston to move downward, causing the pump to increase fuel delivery.

- After the fuel passes through the two orifices, it leaves the compensator through an outlet port. From here the fuel passes back to the pump.

Q10. For what does MITAC stand?

Q11. In a sleeve metering injection system, at what rate does the constant bleed valve return fuel to the fuel tank?

Q12. In a sleeve metering injection system, where is the automatic advance unit mounted?

Q13. In a scroll metering fuel system, where is the transfer pump located?

Q14. What three rotating members revolve on a common axis within a distributor-type fuel injection system ?

Q15. In a distributor-type fuel injection system, what controls the maximum amount of fuel that can be injected?

Q16. What component maintains fuel pressure in the DB2 governor housing?

Q17. At what pressure range does the relief valve on a Detroit diesel engine bypass fuel back to the inlet side of the fuel pump?

Q18. What type of injector is used in a Detroit diesel engine?

Q19. What number of crankshaft revolutions is required to time all the injectors in a two-cycle Detroit diesel engine?

Q20. On a Cummins engine using a PT fuel system, what device is used to control exhaust smoke during acceleration?

Q21. How is the PT pump timed to the engine?

Q22. On a Cummins engine that has a Celect system, the ECM determines engine idle speed at start-up, based on data relayed by what sensor?

Q23. On a Cummins engine that has a Celect system, the gear pump delivers fuel to the fuel manifold at what pressure?

Q24. In the Celect system, what component within the injector receives signals from the ECM that controls the start of injection?

Q25. What type engine uses an American Bosch fuel injection system?

Q26. What device used with the PSB American Bosch fuel injection pump allows the use of fuels with different viscosities and heat ranges?

SUPERCHARGERS AND TURBOCHARGERS

LEARNING OBJECTIVE: *Describe the operation of and the differences between superchargers and turbochargers.*

Supercharging and turbocharging is a method of increasing engine volumetric efficiency by forcing the air into the combustion chamber, rather than merely allowing the pistons to draw it naturally. Supercharging and turbocharging, in some cases, will push volumetric efficiencies over 100 percent.

SUPERCHARGERS

A supercharger is an air pump that increases engine power by pushing a denser air charge into the combustion chamber. With more air and fuel, combustion produces more heat energy and pressure to push the piston down in the cylinder. There are three basic types of superchargers:

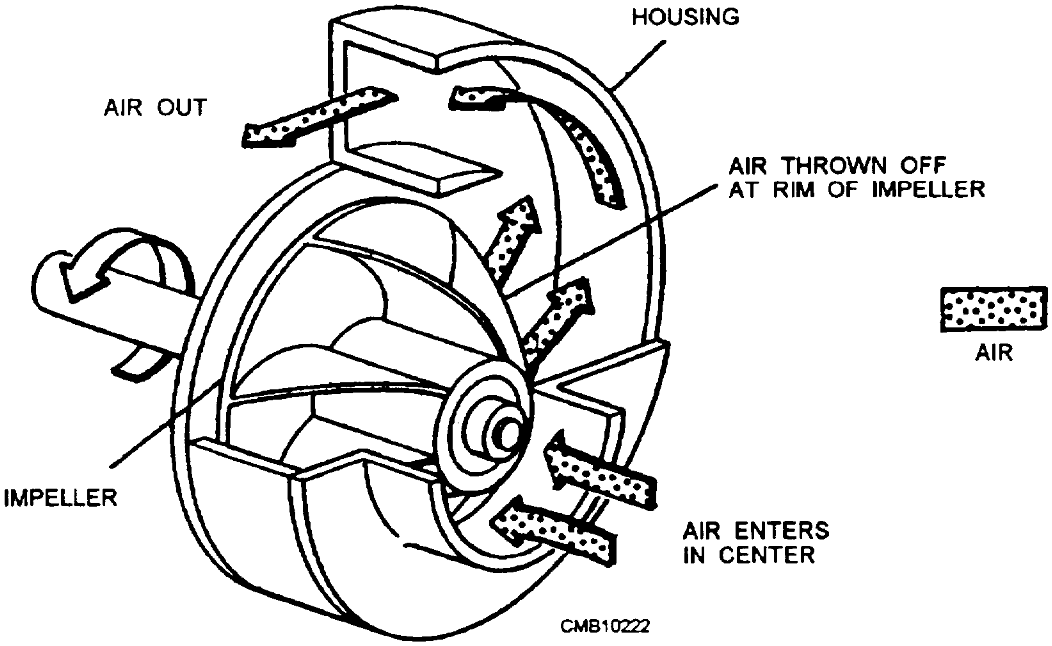


Figure 5-39.—Centrifugal supercharger.

1. **Centrifugal supercharger** (fig. 5-39). The centrifugal supercharger has an impeller equipped with curved vanes. As the engine drives the impeller, it draws air into its center and throws it off at its rim. The air then is pushed along the inside of the circular housing. The diameter of the housing gradually increases to the outlet where the air is pushed out.
2. **Rotor (Rootes) supercharger** (fig. 5-40). The Rootes supercharger is of the positive displacement type and consists of two rotors inside a housing. As the engine drives the rotors, air is trapped between them and the housing. Air is then carried to the outlet where it is discharged. The rotors and the housing in this type of supercharger must maintain tight clearances and therefore are sensitive to dirt.
3. **Vane-type supercharger** (fig. 5-41). The vane-type supercharger has an integral steel rotor and shaft, one end supported in the pump flange and the other end in the cover, and revolves in the body, the bore of which is eccentric to the rotor. Two sliding vanes are placed 180 degrees apart in slots in the rotor and are pressed against the body bore by springs in the slots. When the shaft rotates, the vanes pick up a charge of air at the inlet port, and it is carried around the body to the outlet where the air is discharged. Pressure is produced by the wedging action of the air, as it is forced toward the outlet port by the vane.

The term *supercharger* generally refers to a **blower** driven by a belt, chain, or gears. Superchargers are used on large diesel and racing engines.

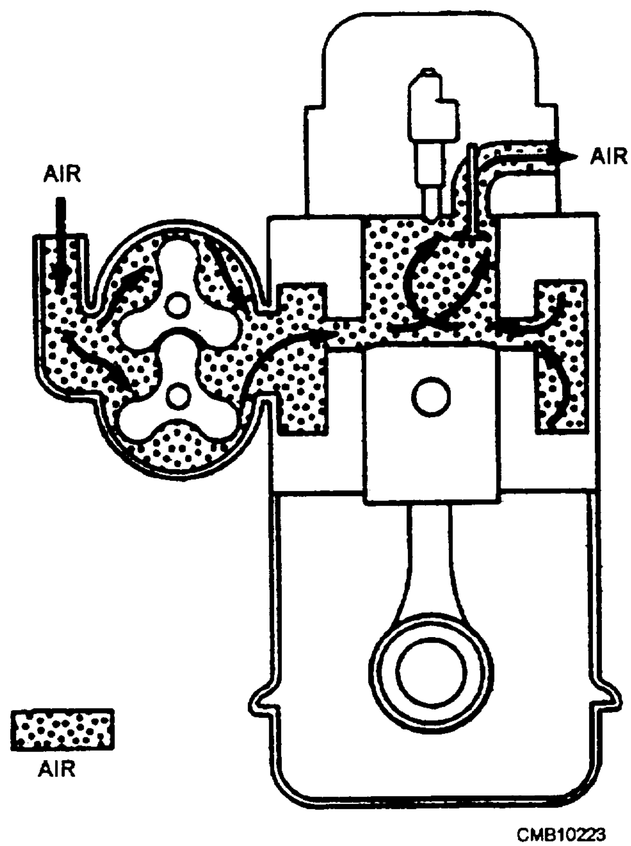


Figure 5-40.—Rootes supercharger.

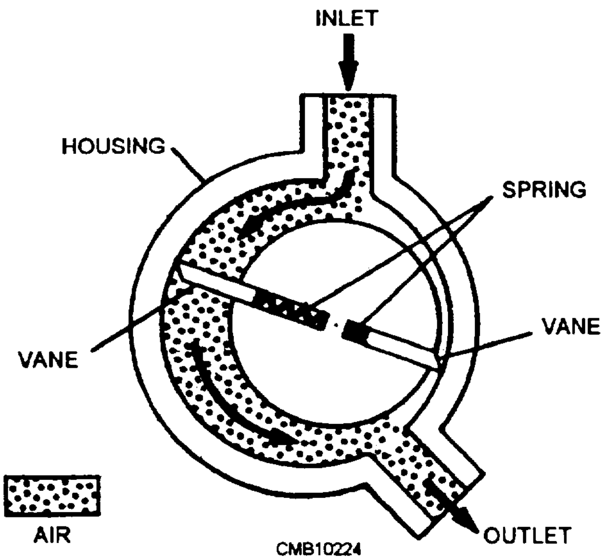


Figure 5-41.—Vane-type supercharger.

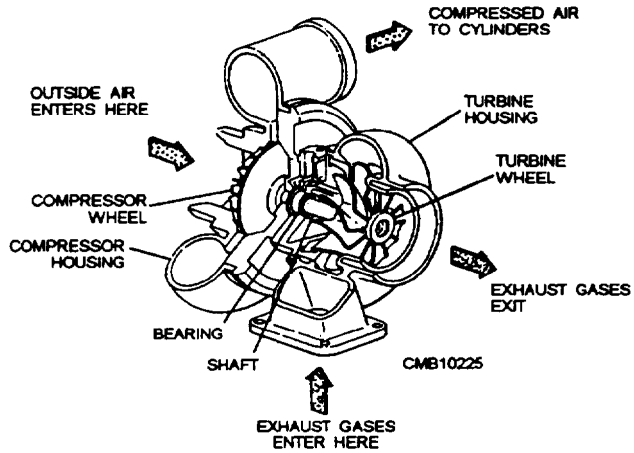


Figure 5-42.—Turbocharger (cutaway view).

The supercharger raises the air pressure in the engine intake manifold. Then, when the intake valves open, more air-fuel mixture (gasoline engine) or air (diesel engine) can flow into the cylinders. An intercooler is used between the supercharger outlet and the engine to cool the air and to increase power (cool charge of air carries more oxygen needed for combustion).

A supercharger will instantly produce increased pressure at low engine speed because it is mechanically linked to the engine crankshaft. This low-speed power and instant throttle response is desirable for passing and entering interstate highways.

TURBOCHARGERS

A turbocharger is an exhaust-driven supercharger (fan or blower) that forces air into the engine under pressure. Turbochargers are frequently used on small gasoline and diesel engines to increase power output. By harnessing engine exhaust energy, a turbocharger can also improve engine efficiency (fuel economy and emissions levels).

The turbocharger (fig. 5-42) consists of three basic parts—a turbine wheel; an impeller or compressor; and housings that support the parts and direct the flow of exhaust gases and intake air. Basic operation of a turbocharger is as follows:

- When the engine is running, hot gases blow out the open exhaust valves and into the exhaust manifold. The exhaust manifold and connecting tubing route these gases into the turbine housing.
- As the gases pass through the turbine housing, they strike the fins or blades on the turbine wheel. When engine load is high enough, there is enough exhaust gas flow to spin the turbine wheel rapidly.
- Since the turbine wheel is connected to the impeller by the turbo shaft, the impeller rotates with the turbine. Impeller rotation pulls air into the compressor housing. Centrifugal force throws the spinning air outward. This causes air to flow out of the turbocharger and into the engine cylinder under pressure.

A turbocharger is located on one side of the engine. An exhaust pipe connects the exhaust manifold to the turbine housing. The exhaust system header pipe connects to the outlet of the turbine housing.

Theoretically, the turbocharger should be located as close to the engine manifold as possible. Then a maximum amount of exhaust heat will enter the turbine housing. When the hot gases move past the spinning turbine wheel, they are still expanding and help rotate the turbine.

Turbocharger lubrication is required to protect the turbo shaft and bearings from damage. A turbocharger can operate at speeds up to 100,000 rpm. For this reason, the engine lubrication system forces oil into the turbo shaft bearings. Oil passages are provided in the turbo housing and bearings and an oil supply line runs from the engine to the turbocharger. With the engine running, oil enters the turbocharger under pressure. A drain passage and drain line allows oil to return to the engine oil pan after passing through the turbo bearings.

Sealing rings (piston-type rings) are placed around the turbo shaft at each end of the turbo housing, preventing oil leakage into the compressor and turbine housings.

Turbochargers require little maintenance between overhauls if the air cleaners are serviced regularly according to the manufacturer's recommendations. The turbocharger turbine requires periodic cleaning to remove carbon deposits that cause an unbalanced condition at the high relative speeds at which the turbine must rotate.

Turbocharging system problems usually show up as inadequate boost pressure (lack of engine power), leaking shaft seals (oil consumption), damaged turbine or impeller wheels (vibration and noise), or excess boost (detonation).

NOTE

Refer to a factory service manual for a detailed troubleshooting chart. It will list the common troubles for the particular turbocharging system.

There are several checks that can be made to determine turbocharging system conditions. These checks include the following:

- Check connection of all vacuum lines to the waste gate and oil lines to the turbocharger.
- Use regulated, low-pressure air to check for waste gate diaphragm leakage and operation.
- Use a dash gauge or a test gauge to measure boost pressure. If needed connect the pressure gauge to the intake manifold fitting. Compare to the manufacturer's specifications.
- Use a stethoscope to listen for bad turbocharger bearings.

Turbo Lag

Turbo lag refers to a short delay before the turbocharger develops sufficient boost (pressure above atmospheric pressure).

As the accelerator pedal is pressed down for rapid acceleration, the engine may lack power for a few seconds. This is caused by the impeller and turbine wheels not spinning fast enough. It takes time for the exhaust gases to bring the turbocharger up to operating speed. To minimize turbo lag, the turbine and impeller wheels are made very light so they can accelerate up to rpm quickly.

Turbocharger Intercooler

A turbocharger intercooler is an air-to-air heat exchanger that cools the air entering the engine. It is a radiator-like device mounted at the pressure outlet of the turbocharger.

Outside air flows over and cools the fins and tubes of the intercooler. As the air flows through the intercooler, heat is removed. By cooling the air entering the engine, engine power is increased because the air is more dense (contains more oxygen by volume). Cooling also reduces the tendency for engine detonation.

Waste Gate

A waste gate limits the maximum amount of boost pressure developed by the turbocharger. It is a butterfly or poppet-type valve that allows exhaust to bypass the turbine wheel.

Without a waste gate, the turbocharger could produce too much pressure in the combustion chambers. This could lead to detonation (spontaneous combustion) and engine damage.

A diaphragm assembly operates the waste gate. Intake manifold pressure acts on the diaphragm to control waste gate valve action. The valve controls the opening and closing of a passage around the turbine wheel.

Under partial load, the system routes all of the exhaust gases through the turbine housing. The waste gate is closed by the diaphragm spring. This assures that there is adequate boost to increase power.

Under a full load, boost may become high enough to overcome spring pressure. Manifold pressure compresses the spring and opens the waste gate. This permits some of the exhaust gases to flow through the waste gate passage and into the exhaust system. Less exhaust is left to spin the turbine. Boost pressure is limited to a preset value.

Q27. What device is used between the supercharger outlet and the engine to cool the air?

Q28. In a turbocharger, what prevents oil from leaking into the compressor and turbine housing?

COLD WEATHER STARTING

LEARNING OBJECTIVE: *Identify the different types of cold weather starting aids.*

Diesel fuel evaporates much slower than gasoline and requires more heat to cause combustion in the cylinder of the engine. For this reason, preheating devices and starting aids are used on diesel engines. These devices and starting aids either heat the air before it is drawn into the cylinder or allow combustion at a lower temperature than during normal engine operation.

GLOW PLUGS

The purpose of a glow plug is to beat up the air that is drawn into the precombustion chamber to assist starting, especially in cold weather. Glow plugs are common on precombustion chamber engines, but not on direct injection diesels because they use shaped piston crowns that produce a very effective turbulence to the air in the cylinder. Direct injection engines also have less immediate heat loss to the surrounding cylinder area than in a precombustion engine and generally have a higher injection spray-in pressure.

A glow plug is used for each cylinder located just below the injection nozzle and threaded into the cylinder head (fig. 5-43). The inner tip of the glow plug extends into the precombustion chamber. The glow plugs may be turned on using the ignition switch with

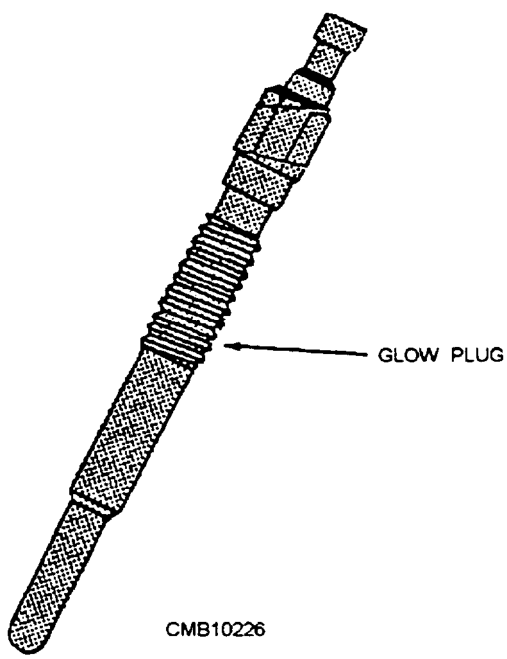


Figure 5-43.—Typcial diesel glow plug.

the length of time being controlled from an electronic module. On some older vehicles and construction equipment, glow plugs are operated by manually depressing a switch or button for 15 to 30 seconds. During colder weather, the system may have to be cycled more than once to start the engine.

Glow plugs are not complicated and are easy to test. Disconnect the wire going to the glow plug and use a multimeter to read the ohms resistance of the glow plug. Specifications for different glow plugs vary according to the manufacturer. Be sure and check the manufacturer's service manual for the correct ohms resistance value.

MANIFOLD FLAME HEATER

The manifold flame heater (fig. 5-44) is another type of cold starting system found on diesel engines. This system is composed of a housing, spark plug, flow control nozzle, and two solenoid control valves. This system operates as follows:

1. The flame heater ignition unit energizes the spark plug.
2. The nozzle sprays fuel under pressure into the intake manifold assembly.
3. The fuel vapor is ignited by the spark plug and burns in the intake manifold. The heat from this fire warms the air before it enters the combustion chamber.

The flame fuel pump assembly is a rotary type, driven by an enclosed electric motor. The fuel pump receives fuel from the vehicle fuel tank through the supply pump of the vehicle and delivers it to the spray nozzle. The on/off switch, located on the instrument panel, energizes the pump.

The intake manifold flame heater system has a filter to remove impurities from the fuel before it reaches the nozzle.

The two fuel solenoid valves are energized (open) whenever the flame heater system is activated. The valves ensure that fuel is delivered only when the system is operating. These valves stop the flow of fuel the instant that the engine or heater is shut down.

NOTE

When troubleshooting or repairing these units, you should consult the manufacturer's service manual.

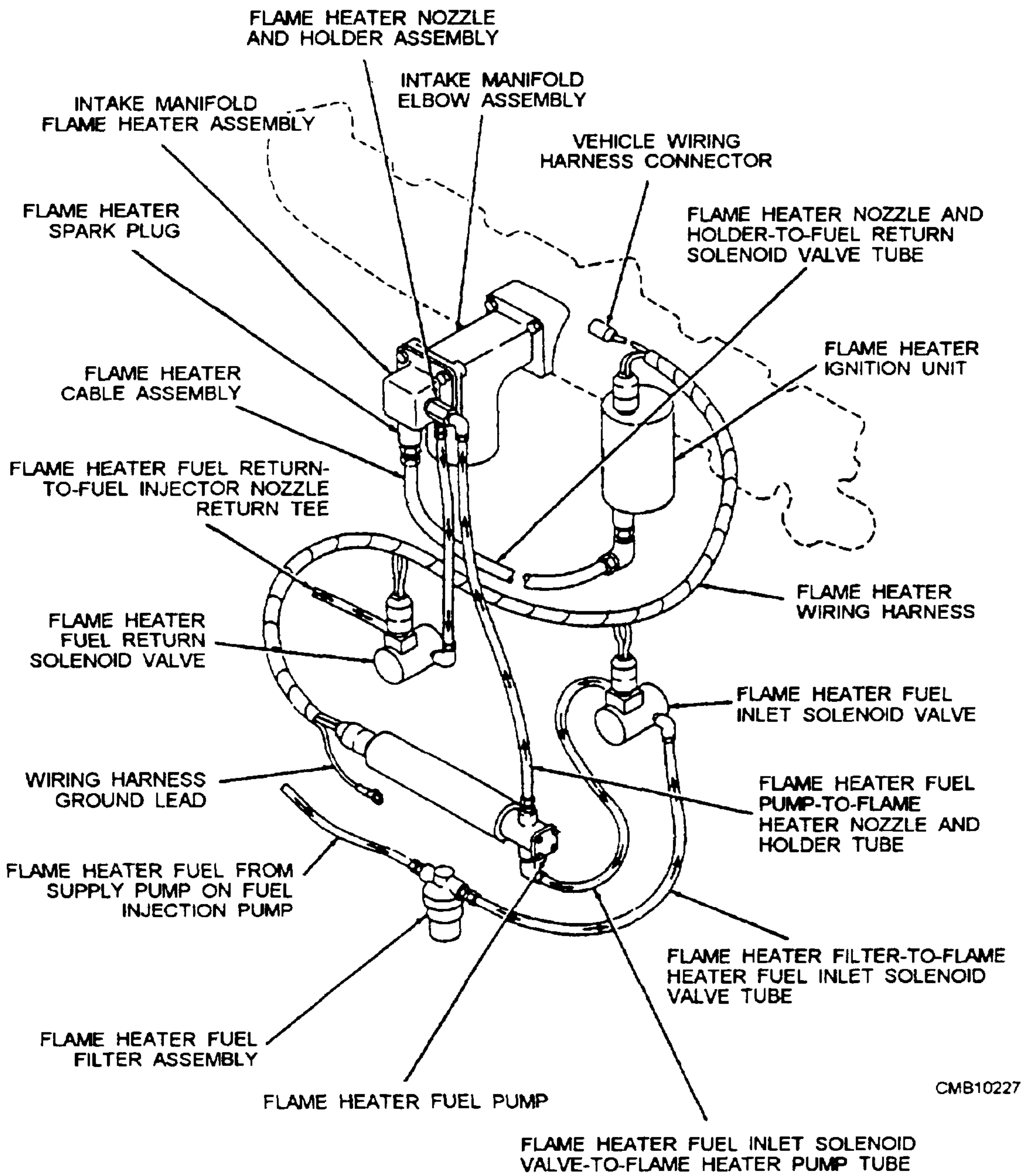


Figure 5-44.—Manifold flame beater system.

ETHER

Ether is a highly volatile fluid that is injected into the intake manifold, as you crank the engine. It is found in an aerosol or capsule type container. Since ether has a low ignition point, the heat generated in the combustion chamber is able to ignite it. Heat from this ignition then ignites the diesel fuel and normal combustion takes place. Once the diesel engine starts, no more fluid is required.

Cold starting aids, such as ether, should be used only in extreme emergencies. Too much ether may detonate in the cylinder too far before top dead center (BDTC) on the compression stroke. This could cause serious damage, such as broken rings, ring lands, pistons, or even cracked cylinder heads. If you must use ether, the engine has to be turning over before you spray it into the intake manifold.

Q29. What cold weather starting system uses a spark plug to ignite fuel vapors in the intakemanifold?

Q30. When should ether be used as a cold starting aid?

DIESEL FUEL SYSTEM MAINTENANCE

LEARNING OBJECTIVE: *Describe the basic maintenance required for a diesel fuel system.*

If all diesel engines had nearly identical fuel system trouble, diagnosis and maintenance procedures could follow a general pattern. But, with the exception of similar fuel tanks and basic piping system, diesel fuel systems differ considerably. Consequently, each engine manufacturer recommends different specific maintenance procedures. However, the tune-up and maintenance procedures described are representative of the job you will do. For all jobs, refer to the manufacturer's service manual for the fuel system you are servicing, even if you fully understand all procedures.

DIRT IN FUEL SYSTEM

Many diesel engine operating troubles result directly or indirectly from dirt in the fuel system. That is why proper fuel storage and handling are so important. One of the most important aspects of diesel fuel is cleanliness. The fuel should not contain more than a trace of foreign substance; otherwise, fuel pump and injector troubles will occur. Diesel fuel, because it is more viscous than gasoline, will hold dirt in suspension for longer periods. Therefore, every precaution should be made to keep the fuel clean.

If the engine starts missing, running irregularly, rapping, or puffing black smoke from the exhaust manifold, look for trouble at the spray nozzle valves. In this event, it is almost a sure bet that dirt is responsible for improper fuel injection into the cylinder. A valve held open or scratched by particles of dirt so that it cannot seat properly will allow fuel to pass into the exhaust without being completely burned, causing black smoke. Too much fuel may cause a cylinder to miss entirely. If dirt prevents the proper amount of fuel from entering the cylinders by restricting spray nozzle holes, the engine may skip or stop entirely. In most cases, injector or valve troubles are easily identified.

Improper injection pump operation, however, is not easily recognized It is more likely caused by excessive wear than by an accumulation of dirt or carbon, such as the spray nozzle is subjected to it in the cylinder combustion chambers. If considerable abrasive dirt gets by the filters to increase (by wear) the small clearance between the injector pump plunger and barrel, fuel will leak by the plunger instead of being forced into the injector nozzle in the cylinder. This gradual decrease in fuel delivery at the spray nozzle may remain unnoticed for some time or until the operator complains of sluggish engine performance.

Although worn injector pumps will result in loss of engine power and hard starting, worn piston rings, cylinder liners, and valves (intake and exhaust) can be responsible for the same conditions. However, with worn cylinder parts or valves, poor compression, a smoky exhaust, and excessive blow-by will accompany the hard starting and loss of power from the crankcase breather.

WATER IN FUEL SYSTEM

It requires only a little **WATER** in a fuel system to cause an engine to miss, and if present in large enough quantities, the engine will stop entirely. Many fuel filters are designed to clog completely when exposed to water, thereby stopping all fuel flow. Water that enters a tank with the fuel or that is formed by condensation in a partially empty tank or line usually settles to the lowest part of the fuel system. This water should be drained off daily.

AIR IN FUEL SYSTEM

Air trapped in diesel fuel systems is one of the main reasons for a hard starting engine. Air can enter the fuel system at loose joints in the piping or through a spray nozzle that does not close properly. Letting the vehicle run out of fuel will also cause air to enter the system. Like water, air can interfere with the unbroken flow of fuel from the tank to the cylinder. A great deal of air in a system will prevent fuel pumps from picking up fuel and pushing it through the piping system. Air can be removed by bleeding the system as set forth in the procedures described in the manufacturer's maintenance manual.

CLEANING INJECTORS

Unless special servicing equipment and repair instructions are available, defective nozzles and pumps are exchanged for new ones. However, in an emergency, and if spray valves or pumps are not too badly worn, they may be returned to a serviceable condition, with minor adjustment, after a thorough cleaning.

Injector spray nozzles or pumps should be disassembled in the field only when no other recourse is available. Whenever possible, they should be removed from the equipment and brought to the shop for repair. The first requirement for the cleaning job is a clean working area.

Use clean diesel fuel for washing the parts. Disassemble one nozzle at a time to prevent mixing of mating parts. Exercise care to prevent damage to nozzle parts. Inspect and clean all parts as they are disassembled. Carbon may be scraped from the outside of the nozzle, but be careful not to mar the edges of the holes (orifices). When cleaning fluid is used to clean the nozzle parts, dip the parts in diesel fuel immediately after cleaning. This will prevent moisture from the hands from marring the highly polished surfaces.

Reaming tools and special drills are provided for cleaning spray nozzle holes. No drills other than those recommended by the manufacturer should be used. The drills are hand-operated, using a cleaning needle that is held in place by a small chuck, called a pin vise (fig. 5-45). In performing reaming operations, remove only the foreign matter; be particularly careful not to burr the metal.

> **WARNING**
>
> Diesel fuel is a hazardous material. Avoid prolonged skin contact and wear goggles. Keep fire and flame away. Dispose of waste material and cleaning rags as hazardous waste. For more information, see OPNAVINST 4110.2, *Hazardous Material Control and Management.*

Q31. When should water be drained from the fuel system?

Q32. What is the first requirement when disassembling an injector for cleaning?

GENERAL TROUBLESHOOTING

LEARNING OBJECTIVE: *Describe general troubleshooting techniques used in the maintenance of a diesel fuel system.*

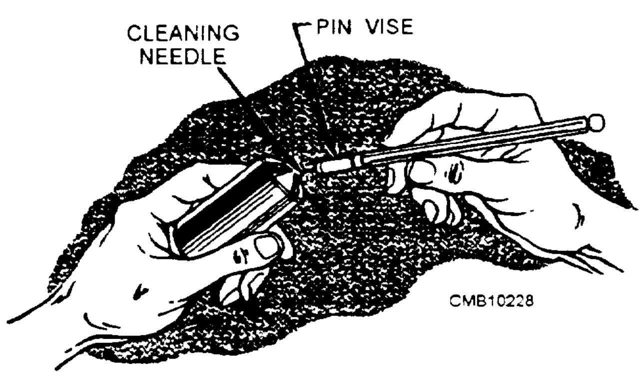


Figure 5-45.—Cleaning injector spray nozzle holes.

When troubleshooting a diesel engine, keep in mind that problems associated with one make and type of engine (two-stroke versus four-stroke) may not occur exactly in the same way as in another. Specifically, particular features of one four-stroke-cycle engine may not appear on another due the type of fuel system used and optional features on that engine. Follow the basic troubleshooting steps listed below before rolling up your sleeves and trying to pinpoint a problem area.

1. Obtain as much information from the operator as possible concerning the complaint.
2. Analyze the problem in detail first, beginning with the smallest and simplest things.
3. Relate the problem symptoms to the basic engine systems and components.
4. Consider any recent maintenance or repair job that might tie into the problem.
5. Always double-check and think about the problem before disassembling anything.
6. Solve the problem by checking the easiest and simplest things first.
7. If possible, use the special tools and diagnostic equipment at your disposal to verify acomplaint and pinpoint the general area.
8. Determine the cause(s) of the problem and carry out the repair.
9. Operate the engine and road test the vehicle to confirm that the problem is corrected.

EXHAUST SMOKE COLOR

One of the easiest methods to use when troubleshooting an engine for a performance complaint is to monitor the color of the smoke coming from the exhaust stack visually. There are four basic colors that may exit from the exhaust system at any time during engine operation—white, black, gray, or blue. The color of the smoke tips you off to just what and where the problem might lie.

- **White smoke** is generally most noticeable at engine start-up, particularly during cold conditions. As the combustion and cylinder temperatures increase during the first few minutes of engine operation the white smoke should start to disappear which indicates the engine is sound. However, if the white smoke takes longer than 3 to 5 minutes to disappear a problem exist. The problems white smoke may indicate are as follows:

- Low cylinder compression from worn rings
- Scored piston or liner
- Valve seating problems
- Water leaking into the combustion chamber
- Faulty injectors
- Use of a low cetane diesel fuel.

- **Black or gray smoke** generally is caused by the same conditions—the difference between the colors being one of opacity or denseness of smoke. Black or gray smoke should be checked with the engine at operating temperature of 160°F. Abnormal amounts of exhaust smoke emission is an indication that the engine is not operating correctly, resulting in a lack of power, as well as decreased fuel economy. Excessive black or gray exhaust smoke is caused by the following:

  - Improper grade of diesel fuel
  - Air starvation
  - High exhaust back pressure
  - Incorrect fuel injection timing
  - Faulty nozzles or injectors
  - Incorrect valve adjustment clearances
  - Faulty injection pump
  - Faulty automatic timing advance unit

- **Blue smoke** is attributed to oil entering the combustion chamber and being burned or blown through the cylinder and burned in the exhaust manifold or turbocharger. Remember always check the simplest things first, such as too much oil in the crankcase or a plugged crankcase ventilation breather. The more serious problems that can cause blue smoke are as follows:

  - Worn valve guides
  - Worn piston rings
  - Worn cylinder walls
  - Scored pistons or cylinder walls
  - Broken rings
  - Turbocharger seal leakage
  - Glazed cylinder liner walls due to use of the wrong type of oil

NOTE

With the engine stopped, the condition of the pistons, rings, and liners on a two-stroke cycle Detroit diesel engine can be checked visually by removing an air box inspection cover on the side of the engine block and accessing the components through the cylinder liner ports.

QUICK INJECTOR MISFIRE CHECK

Listed below are several quick and acceptable checks that can be performed on a running engine to determine if one or more injectors are at fault on any type of engine.

On four-stroke-cycle engines with a high-pressure in-line pump or distributor system, such as Caterpillar and Roosa Master, you can loosen off one injector fuel line, one at a time, about one-half turn as you hold a rag around it while noting if there is any change in the operating sound of the engine. If the injector is firing properly, there should be a positive change to the sound and rpm of the engine when you loosen the line, since it prevents the delivery of fuel to the cylinder.

On an engine with the PT fuel system, a cylinder misfire can be checked by running the engine to a minimum of 160°F, removing the rocker covers, then installing a rocker lever actuator over an injector rocker lever. Hold the injector plunger down while the engine is running at low idle. This will stop the fuel flow to that injector. If the engine speed decreases, the injector is good. If the engine rpm does not decrease, replace the injector.

On the two-stroke-cycle nonelectronic Detroit diesel engines, you can remove the rocker cover, then using a large screwdriver push and hold down the injector follower while the engine is idling. This action is like shorting out a spark plug on a gasoline engine, since it prevents fuel from being injected into the combustion chamber. If there is no change to the sound and speed of the engine, the injector is not firing. There should be a definite change to indicate that the injector was in fact firing.

Q33. After start-up of a cold diesel engine, white smoke dissipates in what number of minutes?

Q34. Oil entering the combustion chamber produces smoke of what color?

Q35. When checking a two-stroke nonelectronic Detroit diesel engine for proper operation, you follow what procedure?